Fishery Data Series No. 07-93

Inriver Abundance of Chinook Salmon in the Kuskokwim River, 2002-2006

Final Report for Study 05-302
USFWS Office of Subsistence Management
Fisheries Division

by
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December 2007

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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INRIVER ABUNDANCE OF CHINOOK SALMON IN THE KUSKOKWIM RIVER, 2002-2006

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ABSTRACT

Two-sample mark-recapture experiments were conducted from early June to late August during 2002-2006 to estimate inriver abundance of Chinook salmon *Oncorhynchus tshawytscha* in the middle and upper Kuskokwim River and associated tributaries using radiotelemetry techniques. For each year, an attempt was made to distribute radio tags such that the radio-tagged fish would be representative of the entire run with respect to temporal abundance, size, sex, and stock composition. Fish were sampled using drift gillnets and fish wheels at various locations above and below Kalskag. Chinook salmon that were captured and radio-tagged constituted the marking event and fish counted at four weirs on tributaries of the Kuskokwim River constituted the second recapture event. Radio-tagged Chinook salmon that migrated past the weirs and were recorded by stationary tracking stations constituted the recaptured portion. Between 97% and 99% of radio-tagged fish were detected by a combination of two aerial surveys and 11 to 17 stationary tracking stations. For 2002-2005, Aniak River bound Chinook salmon were censored from the final estimate due to strong evidence of bank orientation at the marking sites despite moving the capture locations farther downstream from the mouth of the Aniak River. In addition, there were no independent data to evaluate differential probability of capture during the marking event. In 2006, a weir was placed on a tributary of the Aniak River, which allowed for the estimation of a marked:unmarked ratio of Aniak River Chinook salmon. As a result of this second event sampling effort, Aniak River bound Chinook salmon were included in the final estimate for 2006. For the first 3 years of this study an inriver estimate for the Holitna River drainage was calculated using the number of Holitna River bound Chinook salmon that were added to those tagged on this drainage by an independent effort. For 2005 and 2006, an estimate was calculated for Holitna River bound Chinook salmon using only those fish tagged on the mainstem Kuskokwim River. The estimate of abundance for Chinook salmon $\geq$450 mm MEF for the Kuskokwim River upstream of the Aniak River has ranged from 100,733 (SE=24,267) in 2002 to 165,538 (SE=22,660) for 2006. The abundance estimate for 2006 that includes the Aniak River is 233,133 (SE=28,450). The inriver abundance estimate for the Holitna River drainage has ranged from 42,013 (SE=4,981) in 2003 to 89,577 (SE=13,790) for 2006. The majority of radio-tagged Chinook salmon entered the Holitna and Aniak rivers. In general, radio-tagged fish that migrated farther upriver to spawn were captured at the tagging site earlier than those bound for nearby systems.

Key words: Kuskokwim River, Aniak River, abundance estimate, Chinook salmon, *Oncorhynchus tshawytscha*, Holitna River, mark-recapture, radio tag, radiotelemetry, tracking stations, aerial survey

INTRODUCTION

The Kuskokwim River drains a remote basin of about 130,000 km^2 along its 1,130-km course from Interior Alaska to the Bering Sea, and supports five species of Pacific salmon: sockeye salmon *Oncorhynchus nerka*, chum salmon *Oncorhynchus keta*, coho salmon *Oncorhynchus kisutch*, pink salmon *Oncorhynchus gorbuscha*, and Chinook salmon *Oncorhynchus tshawytscha*. Chinook salmon are particularly valued by local subsistence users and account for a large percentage of the total subsistence salmon harvest. In addition, Chinook salmon are one of the most popular species sought out by sport fishers.

The subsistence salmon fishery in the Kuskokwim region is one of the largest and most important in the state (Ward et al. 2003). The directed commercial Chinook salmon fishery in the mainstem Kuskokwim River was discontinued in 1987 by regulation to ensure that subsistence needs would be met. Subsistence fishing occurs along most of the length of the Kuskokwim River with the majority of the harvest and effort taking place in the lower river in the vicinity of Bethel. The commercial fisheries for chum and sockeye salmon, in which Chinook salmon have been harvested incidentally, occur in the lower river in commercial management district W-1.

Salmon runs in the Kuskokwim River drainage are managed for sustained yields under policies set forth by the Alaska Board of Fisheries (BOF) with subsistence use receiving the highest priority. Inseason management has relied on run-strength indices from commercial catch data, test fisheries, and reports from subsistence fishers. The effectiveness of inseason management has been evaluated with aerial surveys and, more recently, ground-based projects. The size, remoteness, and geographic diversity of the Kuskokwim River have presented challenges to monitoring salmon escapements and assessing run strength. Aerial spawning-ground surveys have been the most cost-effective means of monitoring salmon escapements, but their usefulness is limited due to their high degree of variability (Burkey et al. 1999). Ground-based projects such as weirs, counting towers, and sonar have only recently been operated in some locations.

Catch, effort, and harvest for Chinook salmon in the Kuskokwim River drainage from sport fishing is relatively low compared to subsistence and commercial harvests (Table 1). The largest sport fisheries for Chinook salmon occur in the Kisaralik, Kwethluk, Aniak, and Holitna rivers (Chythlook 2006). Since 1985, the average sport harvest of Chinook salmon within the entire Kuskokwim River drainage has varied between 0.07% and 1.64% of the total harvest of this species (Table 1).

From 1998–2000, Kuskokwim area Chinook salmon showed poor escapements compared to previous years and in conjunction, relatively poor subsistence harvests. The 2001 Kuskokwim area Chinook salmon subsistence harvest increased over the relatively poor harvest in 2000. However, when compared to the 10-year period of 1990–1999, the 2001 Chinook salmon subsistence harvest was 11% below average (Burkey et al. 2002). In September 2002, the BOF designated Kuskokwim River Chinook and chum salmon stocks of yield concern under the *Policy for the Management of Sustainable Salmon Fisheries* (5 AAC 39.222, 2001).

The BOF continued the determination of Kuskokwim River Chinook salmon as a stock of yield concern at the BOF meeting in January 2004. This determination was based on the continued inability, despite the use of specific management measures, to maintain expected yields or harvestable surpluses above a stock's escapement needs from 1998 to 2001 (Bergstrom and Whitmore 2004). However, since 2002, Kuskokwim River Chinook salmon runs have shown improvement. The 2002–2006 Chinook and chum salmon runs were large enough to provide for Kuskokwim River subsistence needs (Martz and Dull 2006; Linderman and Bergstrom 2006), while still meeting escapement goals.

As a result of the low escapements from 1998–2001 and the listing of Kuskokwim River Chinook salmon as a stock of concern, funding became available from the Western Alaska Salmon Disaster Grant and from monies administered by the U.S. Fish and Wildlife Service Office of Subsistence Management (OSM) for additional salmon assessment programs in the Kuskokwim River. Many of these projects, as well as ongoing department-funded projects, have focused on assessing escapements in tributary systems. In recent years, weirs have been used to enumerate escapements on the Kwethluk, Tuluksak, George, Kogrukluk, Tatlawiksuk, and Takotna rivers. In addition, from 2001-2004 a mark-recapture study was conducted on the Holitna River to estimate abundance of Chinook salmon in that system (Wuttig and Evenson 2002; Chythlook and Evenson 2003; Stroka and Brase 2004; Stroka and Reed 2005). While these tributary assessment projects have contributed greatly to assessing escapement of Kuskokwim River Chinook salmon, the relative contributions of these tributary escapements to total inriver abundance could not be estimated without a drainage-wide escapement estimate.

Therefore, in 2002 the Kuskokwim River mainstem mark-recapture and radiotelemetry project was implemented to estimate inriver abundance of Chinook salmon in the middle and upper

Table 1.–Estimated sport, commercial, and subsistence harvests of Chinook salmon in the Kuskokwim River drainage, 1985–2006.

	Sport Harvest[a]								
Year	Aniak River	Holitna River	Other Kuskokwim River[b]	Total Sport	Commercial[c]	Subsistence[c]	Bethel Test Fishery	Total Harvest	% Sport Harvest
1985	12	12	61	85	37,889	43,874	79	81,927	0.10%
1986	49	0	0	49	19,414	51,019	130	70,612	0.07%
1987	49	14	292	355	36,179	67,325	384	104,243	0.34%
1988	164	18	346	528	55,716	70,943	576	127,763	0.41%
1989	738	156	324	1,218	43,217	81,176	543	126,154	0.97%
1990	285	0	109	394	53,504	85,979	512	140,389	0.28%
1991	214	0	187	401	37,778	85,554	117	123,850	0.32%
1992	172	23	172	367	46,872	64,795	1,380	113,414	0.32%
1993	300	68	219	587	8,735	87,512	2,483	99,317	0.59%
1994	437	40	662	1,139	16,211	93,242	1,937	112,529	1.01%
1995	279	19	243	541	30,846	96,436	1,421	129,244	0.42%
1996	592	256	584	1,432	7,419	78,063	247	87,161	1.64%
1997	801	166	260	1,227	10,441	81,577	332	93,577	1.31%
1998	1,058	54	322	1,434	17,359	81,265	210	100,268	1.43%
1999	134	25	93	252	4,705	73,194	98	78,249	0.32%
2000	10	22	73	105	444	64,893	874	66,316	0.16%
2001	12	73	205	290	90	73,610	86	74,076	0.39%
2002	135	53	131	319	72	71,334	288	72,013	0.44%
2003	12	48	674	734	150	67,788	409	69,081	1.06%
2004	335	136	726	1,197	2,300	80,065	1,134	84,696	1.41%
2005	189	180	723	1,092	4,784	68,213	883	74,972	1.46%
2006	NA[d]	NA[d]	NA[d]	NA[d]	2,777	NA[d]	NA[d]	NA[d]	NA[d]

[a] Sport fish harvest estimates from Mills (1986-1994), Howe et al. (1995-1996, 2001a-d), Walker et al. (2003), and Jennings et al. (2004, 2006a-b, 2007, *In prep*).

[b] Indicates all sport harvest reported in the Kuskokwim River drainage excluding the Aniak and Holitna rivers.

[c] Commercial and subsistence harvest estimates from Burkey et al. (2002), Ward et al. (2003), Whitmore et al. (2005), and Martz and Dull (2006).

[d] Sport harvest and Subsistence estimates not available.

portions of the drainage (Figure 1). This report summarizes results from 2002-2005 and details 2002-2005 are provided by Stuby (2003-2006). The primary goals of this multi-year study have been to collect estimates of run size and to characterize the age, sex, and length composition for annual returns to the middle and upper portions of the Kuskokwim River drainage.

In addition to an inriver estimate of abundance, radio-tagged Chinook salmon from the mainstem project were used in conjunction with the separate Holitna River mark-recapture project to estimate Chinook salmon abundance in the Holitna River drainage. Between 2002 and 2004, approximately 40%-50% of the Chinook salmon radio-tagged in the mainstem Kuskokwim River traveled into the Holitna River drainage (Chythlook and Evenson 2003; Stroka and Brase 2004; Stroka and Reed 2005). From 2002-2004, radio-tagged Chinook salmon from this mainstem project were included as part of the first event sample in the Holitna River mark-recapture study. However, because of the relatively large number of radio-tagged fish from the mainstem project, it was determined that abundance of Chinook salmon entering the Holitna River could be adequately estimated without the additional tagging efforts in the lower river. Thus, for 2005 and 2006, inriver abundance of Chinook salmon for the Holitna River drainage was estimated solely with radio-tagged fish from the mainstem tagging effort.

Mid-to-upper mainstem inriver abundance estimates have been used in conjunction with escapement monitoring projects in the lower Kuskokwim River (Kwethluk and Tuluksak rivers) and harvest estimates to approximate total returns to the Kuskokwim River between 2002 and 2005 (Molyneaux and Brannian 2006). Total drainage estimates from future run-reconstruction efforts can be used to estimate exploitation rates and refine escapement goals to better aid in the management of subsistence, commercial, and sport fisheries.

OBJECTIVES

Annual project objectives were to:

1. Estimate the abundance of Chinook salmon $\geq$ 450 mm MEF in the Kuskokwim River for all waters upstream of the Aniak River such that the estimate is within ± 25% of the actual value 90% of the time; and,
2. Estimate age, sex, and length compositions of Chinook salmon $\geq$ 450 mm MEF in the Kuskokwim River upstream of the Aniak River such that all estimated proportions are within 5 percentage points of the actual proportions 95% of the time.

In addition, there were four tasks:

3. Estimate the abundance of Chinook salmon that were bound for the Holitna River system;
4. Document Chinook salmon spawning locations within the Kuskokwim River drainage;
5. Collect the axillary process from each radio-tagged Chinook salmon for the ADF&G Genetics Lab for the purpose of identifying stock specific genetic markers; and,
6. Assist ADF&G Commercial Fisheries Division (CFD) with a sockeye salmon radiotelemetry study by providing radiotelemetry expertise, programming the sockeye salmon radio-tag frequencies into the receivers used for the mainstem Kuskokwim River Chinook salmon radiotelemetry project, and coordinating July and August aerial surveys with CFD personnel.

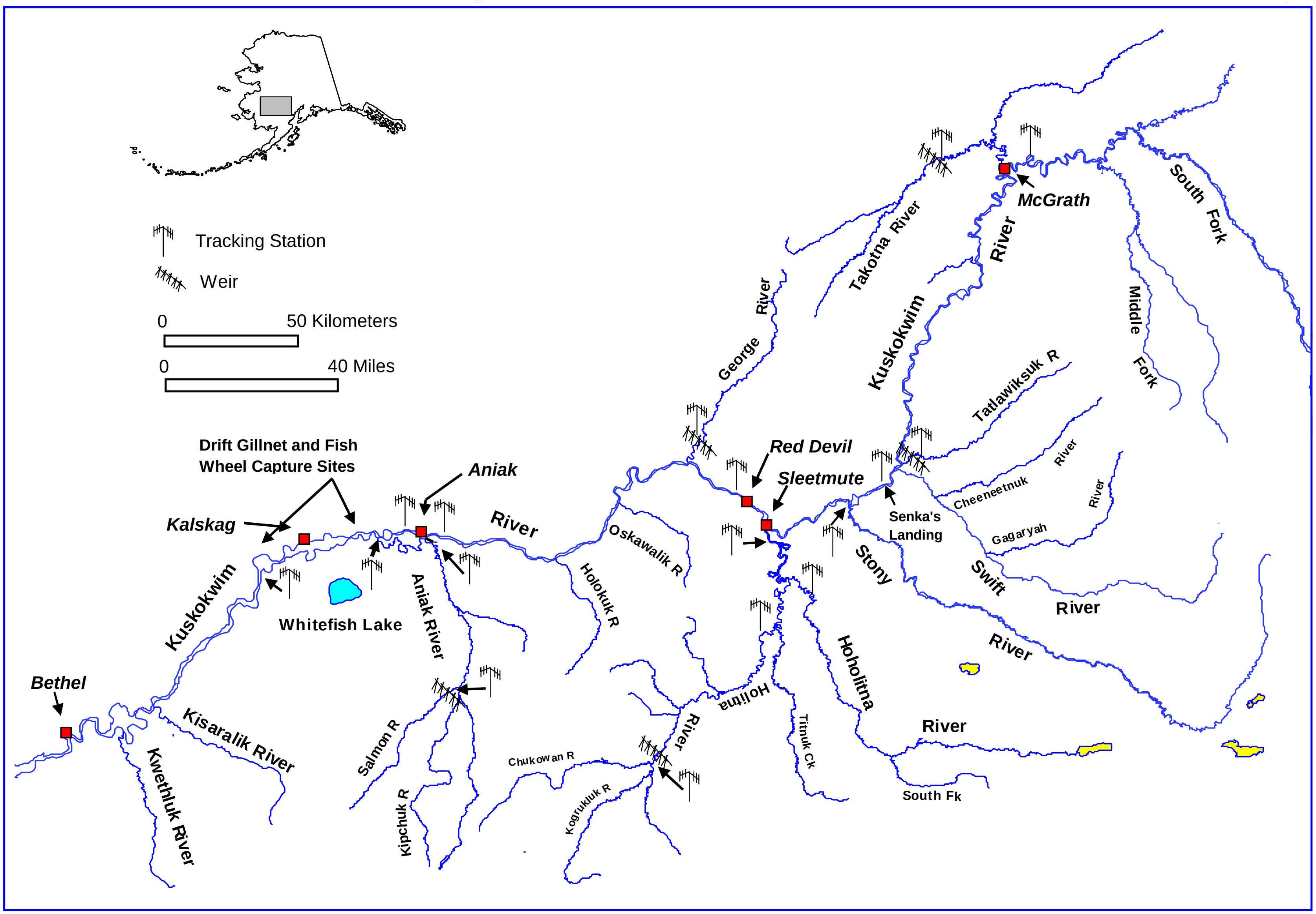

Figure 1.–Map of the Kuskokwim River showing capture sites, weirs, and tracking stations, 2006.

METHODS

During 2002 through 2006, the annual abundance of Chinook salmon returning to the middle and upper Kuskokwim River was estimated using two-sample mark-recapture techniques. Chinook salmon were captured near Kalskag (Figure 1) using drift gillnets and fish wheels throughout the run. Age, sex, and length data were collected from all captured fish. Radio tags were the primary mark and spaghetti tags were the secondary mark. The number of Chinook salmon that retained their radio tags and were detected upstream from the tagging site constituted the first sample. The number of Chinook salmon that passed through weirs on the George, Kogrukluk, Tatlawiksuk, Takotna, and Salmon (in 2006) rivers became the second sample in the mark-recapture experiment. Radio-tagged fish that migrated through the weirs constituted the recaptured portion of the second sample. Age, length, and sex data collected by CFD staff from a sample of the Chinook salmon that passed through each weir were used to test assumptions of equal probabilities of capture. A lottery for cash prizes was conducted to encourage the return of tags and to assist in determining the fates of all radio-tagged Chinook salmon. All subsistence and sport fishers who returned radio and/or spaghetti tags were entered into this lottery. The public was made aware of the study and the lottery through personal contacts and by posting fliers in public places throughout the Kuskokwim area. Each radio tag was labeled with a return mailing address as well as a toll free number to provide catch information and to enter the lottery. Each spaghetti tag was labeled with that same toll free number.

CAPTURE AND TAGGING

The goal of the first sampling event was to capture Chinook salmon and distribute radio tags over the span of the run in proportion to run strength, size composition, and bank of migration. Fishing was conducted six days per week (Sunday-Friday) from start to end of the run. A tag deployment schedule that attempted to distribute tags proportional to run strength was developed based on test net data, which had been collected near Aniak from 1992 to 1995 (Burkey et al. 1997). In addition, weekly tagging goals were determined for small (<650 mm) and large ($\geq$650 mm) Chinook salmon. The number of tags that were deployed in fish of each length category was based on historical length data from the upriver weirs. These data indicated that on average, approximately 20% of the total Chinook salmon escapement past the weirs were <650 mm. Throughout the Chinook salmon run, catches in the Bethel CFD test net fishery were monitored and the tagging schedule was altered in accordance to variations in seasonal run strength. An attempt was made to radio-tag Chinook salmon in equal proportions along the north and south banks of the river to ensure that all spatial components of the run had a non-zero probability of capture. Chinook salmon were sampled with large mesh drift gillnets and fish wheels, which in combination captured a broad size range of fish.

Drift gillnets were fished by a three-person crew from a riverboat along both the north and south banks of the Kuskokwim River near Kalskag. Sampling was conducted at five locations, and use of a particular site varied with water level and debris accumulation (Figure 2). Fishing efforts alternated between banks every 45 min of soak time and half of the daily effort was expended along each bank. Drift gillnetting typically began each day at 1600 hours and continued until 3-hours of fishing time or a 7.5-hour workday was achieved. Three CFD fish wheels were operated 24 hours per day beginning June 1 near Kalskag (Figure 2). Two fish wheels were located along the north bank and one along the south bank of the Kuskokwim River. Each day,

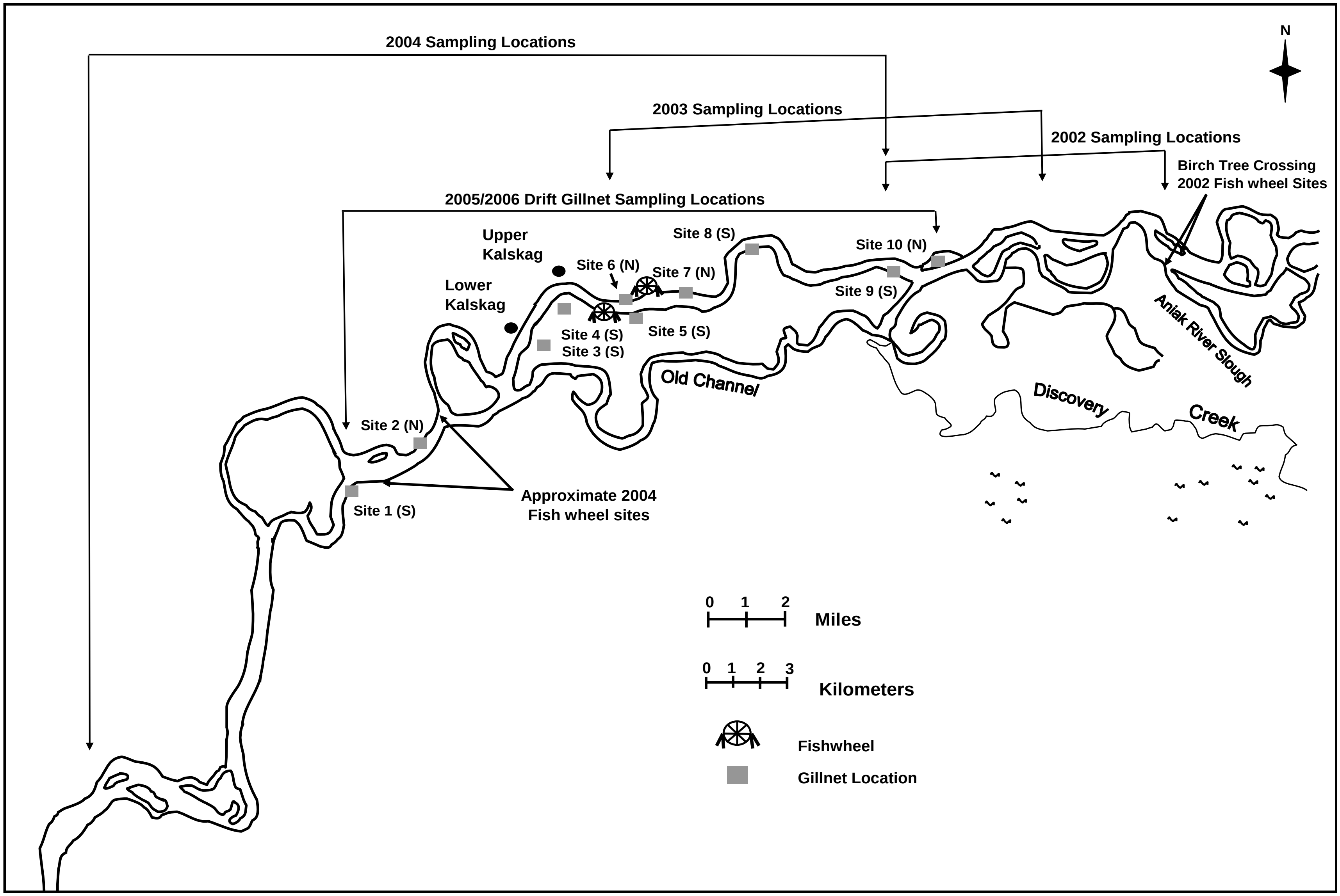

Figure 2.–Map of the drift gillnet and fish wheel tagging locations for Chinook salmon in the Kuskokwim River, 2006, and approximate sampling locations used between 2002 and 2005. An (S) denotes a south bank and an (N) denotes a north bank location.

salmon were sampled from the fish wheel live boxes between the hours of 0600-1430 and 1800-0230.

Drift gillnets were constructed of cable-lay material and were 100 to 150 ft in length. A gillnet with 8.0 in mesh and 29 panels deep was fished in the nearshore reaches. A gillnet with 8.25 in mesh and 45 panels deep was fished in the mid-channel reaches and during high water events early in the season in 2002. When a Chinook salmon was captured in a drift gillnet, the net was immediately retrieved into the boat and the fish was removed from the net and placed into a holding tub. Water in the holding tub was frequently replaced with fresh water, usually after tagging and measuring was completed. All captured fish were measured from mideye to the tail fork (MEF) to the nearest 5 mm.

There has been uncertainty in determining the gender of Chinook salmon between 450 and 620 mm during first event tagging (Stuby 2006). While emerging gender characteristics of near spawning Chinook salmon may be sufficiently advanced at weir sites to allow for accurate gender classification, accurate classification can be more difficult at sites farther downriver such as those used for capture and tagging. This was particularly true for smaller salmon as the normal "male" characteristics (deeper colored, hooked upper jaw, ridged back) of age-1.1 to age-1.2 salmon tend to not be as readily apparent. The CFD personnel operating the weirs have been instructed to be highly critical of assigning captured Chinook salmon as females if they are smaller than 720 mm. This conclusion was based on analysis of 3 years of commercial fishery catch samples that indicated 97.5% of the harvested female Chinook salmon were larger than 719 mm (Linderman et al. 2003). For 2006, gillnet and fish wheel crews were instructed to be critical when examining fish <720 mm before assigning gender and if uncertain, assign the fish as "Unknown".

Three scales were removed from the left side of the captured fish approximately two rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Welander 1940) and placed on gum cards. Scale impressions were later made on acetate cards and then viewed at 100X magnification using equipment similar to that described by Ryan and Christie (1976). Ages were then determined from scale patterns as described by Mosher (1969).

The left axillary process was collected from each radio-tagged Chinook salmon during 2003-2006. Each tissue sample was cleaned and immediately placed in an individually labeled vial filled with 100% ethanol and the vials were stored in a cool, dark place. Later, these tissues were sent to and processed later by the Anchorage CFD genetics laboratory. These samples were added to those from previous years to establish a genetic baseline for Chinook salmon from the Kuskokwim River, identify genetic units for improved conservation and management, and standardize and contribute data to Pacific Rim databases (Templin et al. 2004).

Esophageal-implanted radio transmitters were used as the primary mark for all 5 years of this study and their size (14.5 x 49 mm) precluded applying them to Chinook salmon <450 mm. Winter (1983) recommended against using a transmitter that weighed more than 2% of a fish's total weight. John Eiler (National Marine Fisheries Service, Juneau; personal communication) recommended tagging salmon ≥500 mm, which would ensure compliance with the 2% rule. However, for the 5 years of the project, 65 fish between 455 and 500 mm were given radio tags and of these, only 4 were assumed to have regurgitated their radio tag and/or not survived tagging and handling. Thus fish ≥450 mm MEF had a good probability of surviving the stress of tagging and handling and were included in the sampling efforts. Similar results were found in coho salmon on the Holitna River (Wuttig and Evenson 2002; Chythlook and Evenson 2003).

Radio tags were inserted through the esophagus and into the upper stomach of Chinook salmon with an implant device. The device was a 45-cm piece of polyvinyl chloride (PVC) tubing with a slit on one end to seat the radio transmitter into the device. Another section of PVC that fit through the center of the first tube acted as a plunger to position the radio tag. The radio tag was pushed through the esophagus and into the stomach such that the antenna end was seated 0.5 cm anterior to the base of the pectoral fin. Chinook salmon were tagged while unrestrained in a large tub of water, and tagging was performed without the use of anesthesia. All radio-tagged fish were given a secondary mark of a uniquely numbered, blue spaghetti tag constructed of a 5-cm section of plastic tubing shrunk onto a 38-cm piece of 80-lb monofilament fishing line. The monofilament was sewn through the musculature of the fish 1-2 cm ventral to the insertion of the dorsal fin between the third and forth fin rays from the posterior of the dorsal fin. Fish were then released in quiet water out of the main current. Fish that were obviously injured and/or appeared stressed did not receive a radio tag.

For all 5 years of the project, an attempt was made to sample the Chinook salmon run in accordance with the necessary conditions to produce an unbiased estimate of abundance with the generalized Petersen model. However, for all years Chinook salmon bound for the Aniak River were disproportionately sampled on the south-side bank. Sampling efforts in 2002 were conducted in the vicinity of Birch Tree Crossing, which was located near the outlet of the Aniak River Slough (Figure 2). Nearly 80% of all Aniak River bound Chinook salmon were tagged from the south-side bank, near the slough. Conversely, the north-side fish wheel and drift gillnet sites had captured a much lower proportion of Aniak River bound Chinook salmon compared to the downriver tagging sites. As a result, sampling activities in 2003 were moved downriver, nearer to Kalskag in an attempt to sample and mark salmon downstream from areas where bank orientation was displayed by Aniak River spawners, however bank orientation was still evident. In 2004, sampling activities were moved even farther downriver. The sampling locations in 2004 were poor, in that fewer salmon were caught, and bank orientation was still evident. As a result of experiences in 2002-2004, the capture locations chosen for 2005 and 2006 were the best drift gillnet and fish wheel capture locations of 2003 and 2004, which were a good distance away from the Aniak River slough. More specifically, sampling efforts for 2003, 2005 and 2006 were conducted in a reach approximately 7-8 km above and below Kalskag (Figure 2).

As a result of the bank orientation detected for Aniak River bound Chinook salmon, the data for these fish were excluded in 2002-2005 and the abundance estimates were germane to all waters above the mouth of the Aniak River. Without a substantial second event sampling effort in the Aniak River to estimate the marked:unmarked ratio of Chinook salmon, it was not possible to conduct diagnostic testing to evaluate the potential for sampling bias and/or to identify an appropriate model for estimating abundance which would alleviate bias. In 2006, CFD placed a weir near the mouth of the Salmon River, a major tributary of the Aniak River, in an attempt to acquire a marked:unmarked ratio of Chinook salmon and as a means of enumerating and examining other species of salmon. The weir operated successfully throughout the season and Aniak River bound Chinook salmon were included in the mainstem Kuskokwim River estimate for 2006.

Radio-Tracking Equipment and Tracking Procedures

Radio tags were Model Five pulse encoded transmitters made by ATS[1]. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. Twenty frequencies spaced approximately 20 kHz apart in the 149-150 MHz range with 25 encoded pulse patterns per frequency were used for a total of 500 uniquely identifiable tags.

Radio-tagged Chinook salmon were tracked as they migrated up the Kuskokwim River using a network of 12 (2002) to 17 (2006) ground-based tracking stations similar to those described by Eiler (1995). Each station consisted of a steel housing box which contained two 12 V deep cycle batteries charged by a solar array, an ATS Model 5041 Data Collection Computer (DCC II) and ATS Model 4000 receiver (R4000), or a single R4500 Data Collection Computer and receiver combination. Tag signals were received by two, four element Yagi antennas mounted on a 4-15 m mast (depending on the site) with one facing downstream and one facing upstream so that upstream and downstream movements of fish could be determined. The DCCII/R4000 and R4500 units were programmed to scan through the frequencies at 6-s intervals, and could simultaneously receive from both antennas. When a signal of sufficient strength was detected, the receiver paused for 12 s on each antenna, and then tag frequency, tag code, signal strength, date, time, and antenna number were recorded on the DCCIIs and R4500s. The relatively short cycle period helped minimize the chance that a radio-tagged fish would swim past the station site without being detected. Recorded data were downloaded to a laptop computer every 7–20 days, depending on location.

For 2006, seven tracking stations were located on the mainstem Kuskokwim River: a station was positioned downstream of the capture sites at approximately rkm 264 near the abandoned village of Uknavik; a tracking station was erected near Birch Tree Crossing, one tracking station each was placed immediately above and below Aniak (50-55 rkm above the capture site); one was placed downstream of the Holitna River near Red Devil; one was placed at Senka’s Landing at approximately 605 rkm; and, the seventh tracking station was located just above McGrath (Figure 1). To identify recaptured fish in the mark-recapture experiment, one tracking station was placed at each of the five weir sites on the George, Kogrukluk, Tatlawiksuk, Takotna, and Salmon rivers. In addition, a tracking station was placed near the ADF&G sonar site on the Aniak River at approximately 25 rkm upriver from its confluence with the Kuskokwim River, and one was located near the mouth of the Stony River. Lastly, two tracking stations were located on the mainstem Holitna and Hoholitna rivers, and an additional station was placed near the mouth of the Holitna River.

For 2005, CFD conducted a pilot study on sockeye salmon using radiotelemetry techniques. They used two frequencies with 50 codes on each frequency for a total of 100 unique tags. These frequencies were added to the 14 stationary tracking stations used by Sport Fish Division (SFD) for the mainstem Chinook salmon radiotelemetry projects. For 2006, CFD deployed 500 radio tags. The tracking stations located near Birch Tree Crossing, the mouth of the Stony River, and on the mainstem Kuskokwim River near Senka’s Landing were operated by CFD and incorporated the frequencies from the SFD study. In addition, in 2006, CFD placed a tracking station near the weir on the Salmon River tributary of the Aniak River. Personnel from both

[1] Advanced Telemetry Systems, Isanti, Minnesota (Product names used in this report are included for scientific completeness but do not constitute product endorsement).

divisions cooperated in setting up, downloading, and dismantling the tracking stations at the end of the season.

For 2004-2006, the tracking stations on the mainstem Kuskokwim River near McGrath, Red Devil, and above Aniak as well as tracking stations on the Holitna and Tatlawiksuk rivers, and beginning in 2005, the tracking stations at Senka's Landing and Stony River, were integrated with Satellite High Data Rate (SAT HDR) transmitters. Each hour these transmitters sent information on tracking station status and a portion of the telemetry data collected to a NOAA geostationary operational environmental satellite (GOES). The satellite in turn relayed the data to a receiving station near Washington DC, where the data could then be accessed via the Internet. This system enabled the project leader to check on the operational status of the stations on a daily basis, thereby reducing costs associated with having to travel to the stations.

Aerial-surveys were conducted to locate radio-tagged Chinook salmon in the mainstem Kuskokwim River that did not migrate into a spawning stream (e.g., tag loss or handling mortality), locate tagged fish in spawning tributaries other than those monitored with tracking stations, locate fish that the tracking stations failed to record, and to validate whether a fish recorded on one of the tracking stations did migrate into that particular stream. For the 5 years of the study, two aerial-tracking surveys were conducted in mid-July and mid-August. During each survey, fish were tracked along the mainstem Kuskokwim River, in most of the major tributaries between the capture site and headwaters areas upriver of McGrath, and in all waters upstream of the four weirs. Tracking flights in the upper portion of the Kuskokwim River and in other tributary systems were conducted to the extent possible depending on weather, pilot availability, fuel, and funding constraints. Aerial tracking surveys were conducted with one aircraft, one person (in addition to the pilot), and utilized one R4500 receiver/scanner. All transmitter frequencies were loaded into the receiver/scanner prior to each flight. Dwell time on each frequency was 1-2 seconds. Flight altitude ranged from 100 to 300 m above ground. Two H-antennas equipped with a switching box, one on each wing strut, were mounted such that the antennas detected peak signals perpendicular to the direction of travel. Once a tag was located its frequency, code, and coordinates were recorded by the receiver.

Boat tracking surveys were conducted periodically near the capture/release sites to monitor for tags that had been regurgitated. Keefer et al. (2004) has observed that Chinook salmon that regurgitated their transmitters at or near the release site did so within one day after release. Evenson and Wuttig (2000) observed similar behavior from a radiotelemetry study on the Copper River. During the boat surveys one person monitored a hand-held H-antenna in the front of a boat and another operated an R4500 receiver/scanner.

ESTIMATION OF ABUNDANCE

Assignment of Fate

For the purposes of mark-recapture abundance estimation, every radio-tagged fish was assigned one of five possible fates:

Fate 1: a fish that survived tagging and handling and was harvested above Aniak;

Fate 2: a fish that survived tagging and handling and was detected up a tributary that was not monitored with a weir;

Fate 3: a fish that traveled past one of the tracking stations at weirs on the George, Tatlawiksuk, Kogrukluk, Takotna, and Salmon rivers;

Fate 4: a fish that was known to have migrated upstream past the two tracking stations that were located just above and below Aniak, but was not detected in a major tributary; or,

Fate 5: a fish that was not located either by the tracking stations near Aniak or by aerial means upriver of these tracking stations. Fish of this fate included those that were located or harvested near or downstream of the capture sites (includes fish that regurgitated tags or backed-out), and fish that were never located.

Fish assigned to Fates #1 through #4 were assumed to have survived tagging and handling and were used as the marked sample. Fish assigned Fate #3 constituted recaptured fish. Fates of radio-tagged fish were determined after receiving data from tracking stations, aerial and boat tracking surveys, and from tags returned by fishers. If a fisher returned a radio and/or spaghetti tag or verbally reported harvesting a fish upriver from Aniak, then it was assigned Fate #1. However, fish harvested near or below Aniak were designated as a Fate #5 and censored from the experiment.

Recapture Sample

The second sample for this mark-recapture experiment was the number of Chinook salmon $\geq$450 mm that migrated through the five weirs. This number was estimated from the total Chinook salmon count through the weirs adjusted by the proportion of fish sampled that were $\geq$450 mm. Marked fish in the second sample were fish assigned a Fate #3. At each weir site, only a portion of the Chinook salmon that passed each weir site were handled for the purpose of collecting age, sex, and length (ASL) data. The composition data collected from fish handled at each weir was used to test model assumptions of equal capture probabilities.

Sampling intensity has not been uniform across the weirs during the 5 years of this study. The ASL sample for the Kogrukluk River weir has represented approximately 4% of the total count for Chinook salmon, while the catch sample for the Takotna River weir has represented 6% - 39% of the total count. The catch/total count percentage for the Tatlawiksuk and George river weirs have varied from 8-12% and 3-6% respectively.

Conditions for a Consistent Petersen Estimator

For the estimates of inriver abundance from this mark-recapture experiment to be unbiased, certain assumptions needed to have been fulfilled (Seber 1982). The assumptions, expressed in terms of the conditions of this study, respective design considerations, and test procedures are listed below. To produce an unbiased estimate of abundance with the generalized Petersen model, Assumptions I, II, III and one of the conditions of Assumption IV must have been met.

Assumption I: The population was closed to births, deaths, immigration and emigration.

This assumption was violated because harvest of some fish occurred between events. However, we assumed that marked and unmarked fish were harvested at the same rate. Thus, provided there was no immigration of fish between events, the estimate would remain unbiased with respect to the time and area of the first event (estimate of inriver abundance, not escapement). Sampling in both events encompassed the majority of the run, and any immigration of Chinook salmon past the capture site prior to or after the marking event was assumed to be negligible.

Marked fish that did not migrate upstream past one of the two tracking stations near Aniak were removed from the experiment.

Assumption II: Marking and handling did not affect the catchability of Chinook salmon in the second event.

There was no explicit test for this assumption because the behavior of unhandled fish could not be observed. However, to minimize the effects of handling, holding and handling time of all captured fish was minimized. In a related study, chum salmon tagged and released in the Yukon River immediately after capture in fish wheels resumed upriver movement faster and traveled farther upriver than fish that had been held prior to release (Bromaghin and Underwood 2004). Any obviously stressed or injured fish were not radio-tagged. Radio-tagged fish that were not detected past the two mainstem Kuskokwim River tracking stations near Aniak were removed from the experiment.

Assumption III: Tagged fish did not lose their tags between the tagging site and the weirs.

A combination of stationary tracking stations and aerial and boat tracking surveys were used to identify radio tags that were expelled. In addition, fish inspected at the four weirs were examined for both a spaghetti tag and/or a radio tag. All fish determined to have regurgitated their tags were culled from the analyses.

Assumption IV: Equal probability of capture.

1. All Chinook salmon had the same probability of being caught in the first sampling event;
2. All Chinook salmon had the same probability of being captured in the second sampling event; or,
3. Marked fish mixed completely with unmarked fish between sampling events.

Equal probability of capture was evaluated by size, sex, time, and area. The procedures to analyze sex and length data for statistical bias due to gear selectivity are described in Appendix A1. To further evaluate the three conditions of this assumption, contingency table analyses, recommended by Seber (1982) and described in Appendix A2 were used to detect significant temporal or geographic violations of assumptions of equal probability of capture. Contingency table analyses were also used to test:

1. Equal catchability with respect to tagging location. This test evaluated independence between recapture rates and bank of mark. Independence between bank of mark and bank of recapture and between spawning location and bank of mark were also examined; and,
2. Equal catchability with respect to sampling gear. This test evaluated independence between gear type and recapture rates.

Significant results from these tests are indicative of potential sampling biases which in some cases can be addressed by selecting a stratified model for abundance estimation or by censoring the data.

DATA ANALYSIS

The statistical analysis methods were slightly different in each year of the study. Details from 2006 are reported here. For details of previous year's statistical analyses see Stuby (2003 - 2006).

Because the sampling intensity was not uniform across the four weirs, the sample data were weighted according to passage prior to conducting tests for size and gender bias as described in Appendix A1. Randomization test procedures as described by Manly (1977) were used to evaluate the Kolmogorov-Smirnov (K-S; Conover 1980) two-sample test statistic when weighted observations were used (C vs. R and M vs. C tests in Appendix A1) to test for size bias. To evaluate gender bias using weighted observations, we used empirical Bayesian methods (Carlin and Louis 2000) to evaluate if the proportions of females were different between samples. Using Markov Chain Monte-Carlo techniques, posterior distributions and credibility intervals for the difference in the proportion of females between samples were generated, and the likelihood of erroneously rejecting the null hypothesis (no difference) was evaluated by inspection of the null hypothesis relative to the credibility intervals. When un-weighted observations were used to test for size or gender bias (M vs. R tests in Appendix A1), conventional K-S test and contingency table test procedures were used to evaluate test statistics.

The 2006 estimates of inriver abundance were unstratified for both the mainstem and Holitna River estimates. The Chapman modification to the Petersen estimator (Chapman 1951) was used:

$$\hat{N} = \frac{(\hat{C} + 1)(M + 1)}{R + 1} - 1; \qquad (1)$$

where:

$\hat{N}$ = estimated abundance of Chinook salmon;

M = the number of radio-tagged Chinook salmon known to survive tagging and handling;

R = the number of radio-tagged Chinook salmon moving past the four weirs; and,

$\hat{C}$ = the estimated number of Chinook salmon ≥450 mm MEF counted past the four weirs.

The estimated number of Chinook salmon ≥450 mm MEF that passed the four weirs was calculated as the sum of estimates for each weir:

$$\hat{C} = \sum_{w=1}^{W} \hat{C}_w . \qquad (2)$$

At each weir, passage was estimated:

$$\hat{C}_w = \hat{p}_w C_w \qquad (3)$$

where the proportion of salmon ≥450 mm MEF was estimated from length composition data collected at the weir:

$$\hat{p}_w = n_{C450w} / n_{Cw} \tag{4}$$

and where:

n_{C450w} = number of Chinook salmon ≥450 mm MEF observed of those sampled for composition at weir w, w = 1 to W;

n_{Cw} = the total number of Chinook salmon sampled for composition at weir w; and,

C_w = the number of Chinook salmon counted past weir w when the weir was operational.

Variance and 95% credibility interval for the estimator (equation 1) were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, a posterior distribution for $\hat{N}$ was generated by collecting 200,000 simulated values of $\hat{N}$ which were calculated using equations (1-4) from simulated values of equation parameters. Simulated values were modeled from observed data using the following distributions:

observed n_{C450w} ~binomial (p_w , n_{Cw}); and,

observed R ~binomial (q, M), s = 1 to S;

where q is the probability that a radio-tagged salmon passed one of the weirs and was treated as a recapture.

At the end of the iterations, the following statistics were calculated:

$$\overline{N} = \frac{\sum_{b=1}^{200,000} \hat{N}_{(b)}}{200,000} \text{ ; and,} \tag{5}$$

$$V\hat{a}r(\hat{N}') = \frac{\sum_{b=1}^{200,000} (\hat{N}_{(b)} - \overline{N})^2}{200,000 - 1} \tag{6}$$

where $\hat{N}_{(b)}$ is the bth simulated observation.

Age, Sex, and Length Compositions

The proportions and numbers of Chinook salmon by ocean-age or sex were estimated from first event sample data. Stratification to eliminate size and gender bias was not necessary in 2006, based on the results of diagnostic tests described in Appendix A1. Overall proportions and total numbers were then calculated:

$$\hat{p}_k = \frac{n_k}{n} \tag{7}$$

where:

$\hat{p}_k$ = estimated proportion of Chinook salmon in group k (k = 1 to K);

n_k = number of sampled Chinook salmon in group k; and,

n = number of sampled Chinook salmon in the first event sample.

Variances for the estimates of $\hat{p}_k$ were estimated using (Cochran 1977):

$$v\hat{a}r(\hat{p}_k) = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{8}$$

Mean lengths and associated sampling variances were calculated for each sex and associated age class *k* using standard sample summary statistics (Cochran 1977). The data files used to estimate the parameters of the Chinook salmon population are listed and described in Appendix B.

RESULTS

Specific results from 2006 are presented here. Several tables and figures include results from 2002-2005 for comparison when appropriate. Details of the 2002-2005 results can be found in Stuby (2003-2006).

Five hundred six Chinook salmon were captured and radio-tagged in 2006. Six extra tags were redeployed from the 500 available from those returned by local subsistence fishers. Of the total radio tags deployed, 46% were deployed in fish captured on the north bank and 54% were deployed in fish captured on the south bank.

The Chinook salmon run for 2006 was late compared to the previous seasons. The Kuskokwim River broke up approximately 12 days later than average between Kalskag and Bethel. Even though the fish wheels became operational on June 1 and crews were drifting, the first fish was not captured and radio-tagged until June 7. The daily number of deployed radio tags generally followed the predetermined sampling schedule, with variations due to capture locations, annual run strength, and environmental factors such as timing of river break up and flooding. In general, the sampling objectives were met for tagging fish in the two size classes with respect to bank of capture and size class from 2002-2006 (Appendices C1 and C2). For 2006, 33% of the 506 Chinook salmon that were captured and radio-tagged were <650 mm and 67% were $\geq$ 650 mm.

Fates were described for the 506 radio-tagged fish in (Table 2). Fifty-two radio-tagged fish either lost their tags, were harvested below Aniak, or were never located after tagging (Fate #5). Four hundred fifty four radio-tagged fish were known to have retained their tags and migrated upstream of the capture site (Fates #1 - #4). Of the 53 fish that were recorded past the two mainstem Kuskokwim River tracking stations near Aniak but were never located in a tributary (Fate #4), 32 were recorded by the mainstem Kuskokwim tracking station at Red Devil. The combination of the stationary tracking stations along with the two aerial tracking surveys located 99% of the 506 radio-tagged Chinook salmon. Of these, 456 were detected during one or both aerial surveys. Ninety-six percent of radio-tagged fish were detected by the stationary tracking stations. Three fish were not detected after tagging by any means.

In 2006, the second event sample was comprised of counts from four of the five weirs when the weirs were operational. High water events due to heavy precipitation in mid-August precluded acquiring counts for the George River weir from August 18 - 25, Kogrukluk River weir from August 12 - 24, and Tatlawiksuk River weir after August 19. The Salmon River weir operations ended prior to the precipitation on August 8. Only the actual daily counts were used in the analyses.

Table 2.–Final fates of Chinook salmon radio-tagged in the Kuskokwim River, 2002-2006.

		Number of Radio-tagged Chinook Salmon Assigned This Fate				
Fate #	Fate Description	2002[a]	2003	2004	2005	2006
	Fish that survived tagging and handling					
1	Fish harvested above Aniak.	16	10	2	10	8
2	Fish detected up a tributary that was not monitored with a weir or one of the tributaries with weirs when the weir was not operational.	304	304	211	248	333
3	Fish that traveled past one of the four tracking stations at weirs on the George, Tatlawiksuk, Kogrukluk, Takotna, and/or Salmon rivers during operation and were designated a recapture.	33	55	39	68	60
4	Fish that were detected upriver from the tracking station above Aniak, but were not detected into a tributary.	56	77	56	71	53
	Fish that migrated past the Red Devil tracking station.	46	62	28	37	32
	Fish that did not migrate past the Red Devil tracking station.	10	15	28	34	21
	Subtotal	409	446	308	397	454
5	**Fish not detected upstream of the tracking stations near Aniak**					
	Fish harvested below Aniak.	6	14	14	11	9
	Fish that were not detected by any of the tracking stations and/or by aerial means.	9	3	10	10	3
	Fish that traveled past downriver station near Uknavik and were never recorded again.	3[b]	9	21	9	7
	Fish that remained upstream of Uknavik, but remained downstream of Aniak.	34	26	28	22	33
	Subtotal	52	52	73	52	52
	Total number of fish that were radio tagged.	**461**	**498**	**381**	**449**	**506**

a Fate #2, #4, and #5 values updated from Stuby (2003) and correctly reported in Stuby (2005). Change did not affect the number of marked fish used in the estimator.

b Fish detected by aerial means only.

Sixty radio-tagged Chinook salmon swam past the tracking stations at four of the five weir sites and became part of the recapture portion of the sample. Of these, 35 swam past the Kogrukluk River weir. No radio-tagged fish swam past the Takotna River weir and subsequently the weir counts and ASL information were not included in the analyses.

In general the radio-tagged Chinook salmon that had the farthest to travel (e.g., above McGrath and to the Takotna River) were captured earlier than Chinook salmon returning to rivers closer to the tagging sites (e.g., the Aniak River). However, for all years of this project there has been considerable overlap in the run-timing among the various stocks (Figure 3). Travel times from the capture sites near Kalskag to the tracking stations have also been highly variable and, as expected, mean travel time usually increased for those stations placed farther upriver (Figure 4). Mean travel times to the tracking stations placed just above the four weirs has showed a lag between the time fish reached the weir (time when signal was first received by the downstream antenna) and the time they migrated upstream past the weir (time when signal was last received by upstream antenna) of between two and nine days (Figure 5).

MARK-RECAPTURE EXPERIMENT

A series of diagnostic tests were conducted to evaluate the assumption that all fish, regardless of stock, would have equal probability of capture during the first event and that use of weir counts for the second event would not result in apparent violations of that assumption relative to all Kuskokwim river stocks. For all 5 years of the study, majority of radio-tagged Chinook salmon that migrated into the mid to upper Kuskokwim River tributaries (Fates #2 and #3) traveled into the Holitna and Aniak river systems (Table 3; Appendix D).

During 2006, as was similar in previous years, the majority (72%) of Aniak River bound Chinook salmon were captured at south bank capture sites. However, for 2006, unlike previous years, approximately 50% of Aniak River bound Chinook salmon were captured at the north and south banks using drift gillnet techniques (Table 3), with the disparity seen mainly with fish captured with fish wheels. From 2002-2005, the null hypothesis that bank of mark was independent of spawning location for radio-tagged fish was rejected. However, in those years no sampling was conducted on the Aniak River to evaluate the fraction of the population that was being marked relative to the other spawning areas. Because a weir was operated on the Salmon River tributary of the Aniak River in 2006, the marked:unmarked ratio of Chinook salmon from the Aniak River could be compared to those from the George, Tatlawiksuk, and Kogrukluk river weirs (Table 4; χ^2 = 1.01, df = 1, P = 0.31). Despite the bank orientation of Aniak-bound Chinook salmon, the results of this test indicated that the radio tags were distributed uniformly among the fish bound for all four spawning areas. Thus, the Aniak River bound Chinook salmon could be added to the data set and included in the final analyses. Similarly, when the nine Salmon River Chinook salmon were included in the analysis with the 51 recaptured fish that traveled into the George, Kogrukluk, and Tatlawiksuk rivers, no lack of independence was detected between the bank of mark with their final bank of recapture (Table 5; χ^2 = >0.01, df = 1, P = 0.97).

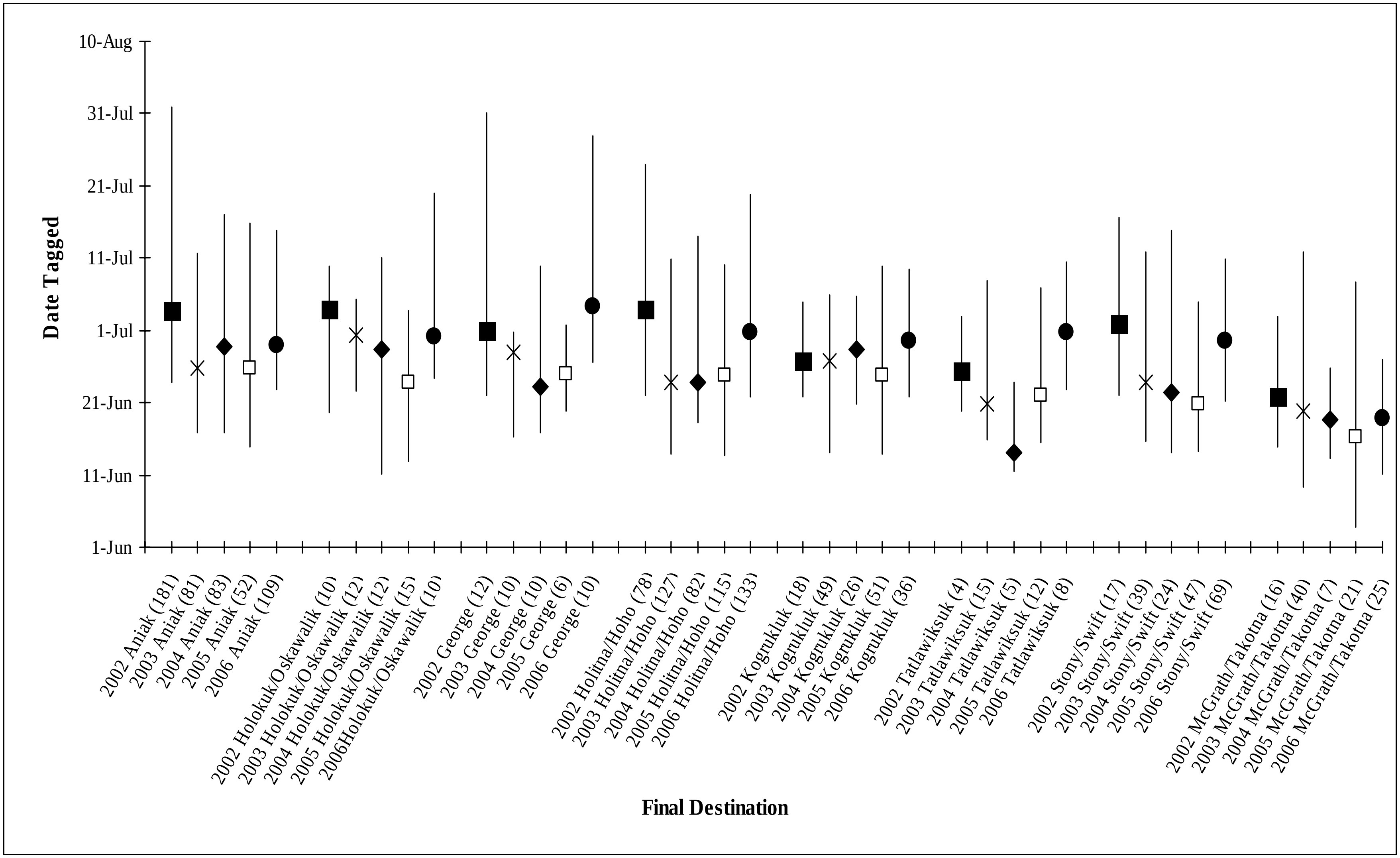

Figure 3.–Median dates of capture (symbol) and 80% range (vertical lines) of Chinook salmon from the Kuskokwim River of known final destinations, 2002-2006. The numbers of fish located in each tributary are presented in parentheses.

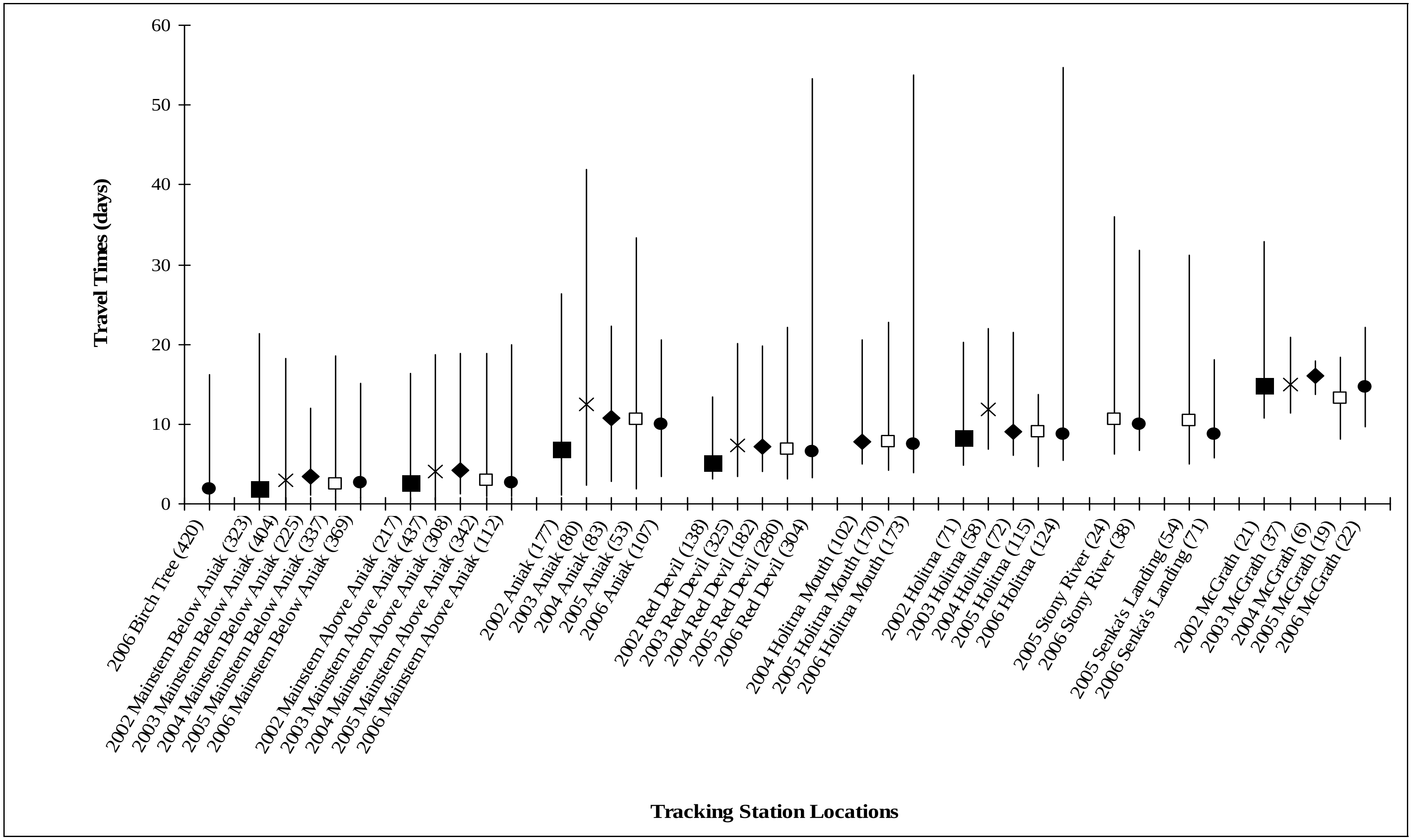

Figure 4.–Mean travel times (symbols) and minimum and maximum travel times (vertical lines) from the capture sites near Kalskag to the stationary tracking stations. The numbers of fish recorded at each tracking station are presented in parentheses.

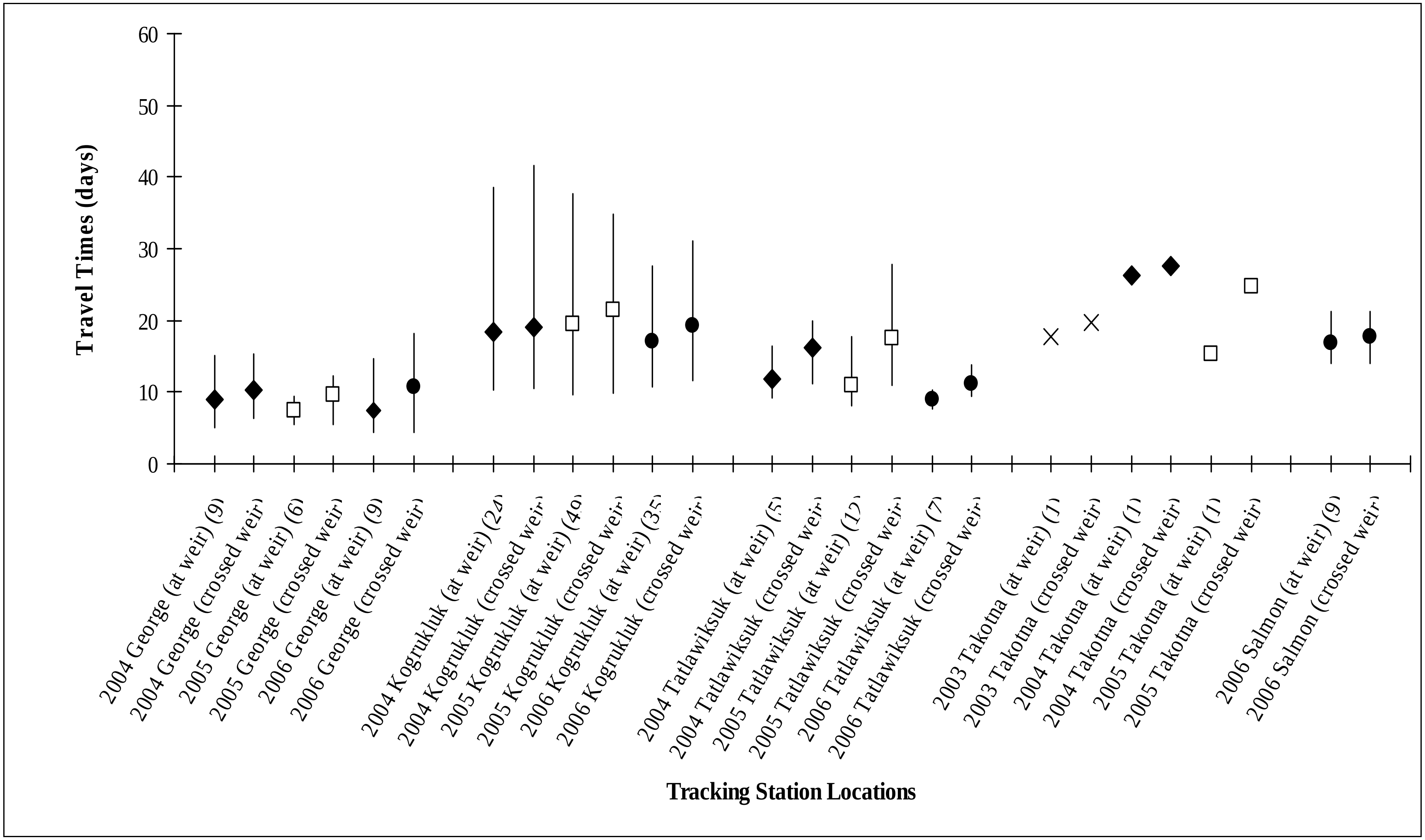

Figure 5.–Mean travel times (symbols) and minimum and maximum travel times (vertical lines) from the capture sites near Kalskag to the five weirs showing time of arrival to the weirs and time when fish passed upstream of the weirs. The numbers of fish recorded at each tracking station are presented in parentheses. For 2002 and 2003, technicians at the George, Kogrukluk, and Tatlawiksuk river weirs collected most of the radio tags from the Chinook salmon before the fish could cross the weir. This along with high water events precluding use of many fish as recaptures, the arrival and crossing times for these years are not included.

Table 3.–Tagging locations and final destinations of radio-tagged Chinook salmon in the Kuskokwim River, 2002-2006.

									2006					
	2002		2003		2004		2005[c]		Fish Wheel		Gillnet			
River	Total	% Total	Total	% Total	Total	% Total	Total	% Total	North	South	North	South	Total	% Total
Holitna	52	16%	82	16%	47	12%	71	22%	8	21	34	33	97	24%
Hoholitna	26	8%	45	9%	35	9%	44	14%	4	8	16	8	36	9%
Kogrukluk	18	5%	49	10%	26	7%	51	16%	2	9	18	7	36	9%
Holitna River Drainage	96	29%	176	35%	108	28%	166	52%	14	38	68	48	169[d]	42%
Aniak	181	39%	81	16%	83	22%	52	16%	7	55	23	24	109	27%
Swift	14	3%	34	7%	17	4%	24	7%	6	4	14	7	31	8%
George	12	3%	10	2%	10	3%	6	2%	1	3	4	2	10	2%
Holokuk	3	1%	5	1%	10	3%	7	2%	2	0	0	1	3	1%
Stony	3	1%	7	1%	7	2%	23	7%	5	11	11	11	38	9%
Above McGrath[a]	15	3%	34	7%	6	2%	19	6%	4	6	8	6	24	6%
Tatlawiksuk	4	1%	15	3%	5	1%	12	4%	3	0	4	1	8	2%
Oskawalik	7	2%	7	1%	2	1%	8	2%	3	2	1	1	7	2%
Takotna	1	<1%	6	1%	1	<1%	2	1%	0	0	1	0	1	<1%
Vreeland	0	0%	1	<1%	0	0%	2	1%	1	0	1	0	2	<1%
Selatna	1	<1%	0	0%	0	0%	0	0%	0	0	1	0	1	<1%
Sue Creek	0	0%	0	0%	1	<1%	0	0%	0	0	0	0	0	0%
Black	0	0%	0	0%	0	0%	1	<1%	0	0	0	0	0	0%
Inriver Harvest	16	3%	7	1%	2	1%	9	2%	0	2	2	0	4	2%
Unknown Final Destination[b]	56	12%	65	13%	56	15%	66	15%	6	9	19	13	47	15%
Undetermined Fate	52	11%	52	10%	73	19%	52	12%	8	20	13	11	52	11%
ALL	**461**		**498**		**381**		**449**						**506**	

[a] Above McGrath Chinook salmon includes fish that were not detected into a tributary and one inriver harvest.

[b] Excludes Chinook salmon that were detected by the tracking station near McGrath.

[c] The relative increase in Stony River bound Chinook salmon in 2005 and 2006 was due to a more comprehensive aerial coverage of this area.

[d] One Holitna River drainage bound Chinook salmon sampled with a gillnet of unknown bank of capture.

Table 4.–Contingency table analysis comparing the marked to unmarked ratios of Chinook salmon that were counted at the George, Tatlawiksuk, and Kogrukluk river weirs with those counted at the Salmon River weir in the Aniak River, 2006.

	Final Destinations		
Weir	Marked	Unmarked	Total Catch
George, Tatlawiksuk, and Kogrukluk Rivers	51	25,188	25,239
Salmon (Aniak River)	9	6,384	6,393
Total Catch	60	31,572	31,632
	χ^2 = 1.01, df = 1, P =0.31		

Table 5.–Contingency table analysis examining independence of bank of marking with bank of recapture for Chinook salmon captured and radio-tagged in the Kuskokwim River, 2006.

	Bank Recaptured		
Bank Marked	North (George River)	South (Kogrukluk, Tatlawiksuk, and Salmon rivers)	Total Recaptured
North	5	28	33
South	4	23	27
Total Recaptured	9	51	60
	χ^2 = <0.01, df = 1, P = 0.97		

The potential for temporal/geographic violations of the assumption of equal probability of capture were examined during the marking event by evaluating the null hypothesis that marked to unmarked ratios observed during second event sampling were independent of sampling locations. No difference was detected between the marked to unmarked ratios of Chinook salmon counted at the George, Kogrukluk, Tatlawiksuk, and Salmon river weirs (Table 6; χ^2 = 5.36, df = 3, P = 0.15). While this result is sufficient to support the use of a Petersen-type model for abundance estimation (see Appendix A2), further tests were conducted to evaluate the potential for temporal/geographic violations of equal probability of capture during second event sampling. No significant evidence was found to reject the null hypothesis that the probability that a tagged fish was later "recaptured" at a weir was independent of bank of mark (Table 7; χ^2 = 2.19, df = 1, P = 0.14) or independent of gear type (Table 8; χ^2 =0.34, df = 1, P = 0.56). Also, we failed to reject the null hypothesis that time of marking during the first event was independent of probability of recapture during the second event when examining all Chinook salmon marked from the first event (Table 9; χ^2 = 2.09, df = 3, P = 0.55) and when examining only that portion that traveled up the Holitna River drainage (χ^2 = 3.97, df = 3, P = 0.26).

Table 6.–Contingency table analysis comparing marked to unmarked ratios of Chinook salmon counted at the George, Kogrukluk, Tatlawiksuk, and Salmon river weirs during the mark-recapture experiment in the Kuskokwim River, 2006.

River	Unmarked	Marked	Total Catch
George	4,346	9	4,355
Tatlawiksuk	1,693	7	19,184
Kogrukluk	19,149	35	1,700
Salmon (Aniak)	6,384	9	6,393
Total Catch	31,572	60	31,632
	χ^2 = 5.36, df = 3, P = 0.15		

Table 7.–Contingency table analysis comparing recapture rates of Chinook salmon marked on the north and south banks of the Kuskokwim River during the mark-recapture experiment, 2006.

	Bank Marked		
Capture History	North	South	Total Marked
Recaptured	33	27	60
Not Recaptured	176	217	393
Total Marked	209	244	453
	χ^2 = 2.19, df = 1, P = 0.14		

Table 8.–Contingency table analysis comparing recapture rates of Chinook salmon by gear type during the mark-recapture experiment on the Kuskokwim River, 2006.

	Sampling Gear		
Capture History	Gillnet	Fish Wheel	Total Marked
Recaptured	38	22	60
Not recaptured	234	160	394
Total Marked	272	182	454
	$\chi^2 = 0.34$, df = 1, $P = 0.56$		

Table 9.–Contingency table analysis testing equal catchability by time for Chinook salmon sampled during the mark-recapture experiment in the Kuskokwim River and for the Holitna River, 2006.

Date Tagged	Not Recaptured	Recaptured	Total Marked
Middle and Upper Kuskokwim River			
7 – 24 June	102	15	117
25 – 28 June	97	13	110
29 June – 2 July	80	17	97
3 July – 14 August	115	15	130
Total	394	60	454
	$\chi^2 = 2.09$, df = 3, $P = 0.55$		
Holitna River			
12 – 24 June	31	7	38
25 – 29 June	33	14	47
30 June – 6 July	36	9	45
7 July – 5 August	34	5	39
Total	134	35	169
	$\chi^2 = 3.97$, df = 3, $P = 0.26$		

The potential for gender bias during second event sampling was examined by testing the null hypothesis that the probability that a marked fish was "recaptured" was independent of gender (Table 10; χ^2 = 0.30, df = 1, P = 0.59). This independence was also seen for those Chinook salmon bound for the Holitna River drainage (Table 10; χ^2 = 0.49, df = 1, P = 0.49). The potential for gender bias during the marking event was examined by testing the null hypothesis that the proportion of females in the sample of "recaptured" fish was the same as the estimated proportion of females $\geq$450 mm in the second event sample at the four weirs. Because the number of unmarked fish $\geq$450 mm passing through the weirs was estimated, the age, sex, and length "catch" data from the weirs was weighted and empirical Bayesian methods (Carlin and Louis 2000) were used to test the null hypothesis. The null hypothesis was not rejected (P = 0.17), which indicated a Case I situation (Appendix A1).

Table 10.–Contingency table analysis of recapture rates of male and female Chinook salmon sampled during the mark-recapture experiment in the Kuskokwim River and for the Holitna River, 2006.

Capture History	Male	Female	Total
Middle-Upper Kuskokwim River			
Recaptured	33	25	58
Marked	231	204	435
Total	264	229	493
	χ^2 = 0.30, df = 1, *P* = 0.59		
Holitna River			
Recaptured	20	14	34
Marked	518	283	801
Total	538	297	835
	χ^2 = 0.49, df = , *P* = 0.49		

The potential for size bias during second event sampling was examined by testing the null hypothesis that there was no difference between the length distributions of Chinook salmon marked during the first event and those "recaptured" during the second event. A significant difference was not detected when we examined all fish (D = 0.08, P = 0.81; Figure 6). Similarly, no difference was detected when we examined only those Chinook salmon bound for the Holitna River drainage (D = 0.16, P = 0.35; Figure 6). Because the age, sex, and length "catch"

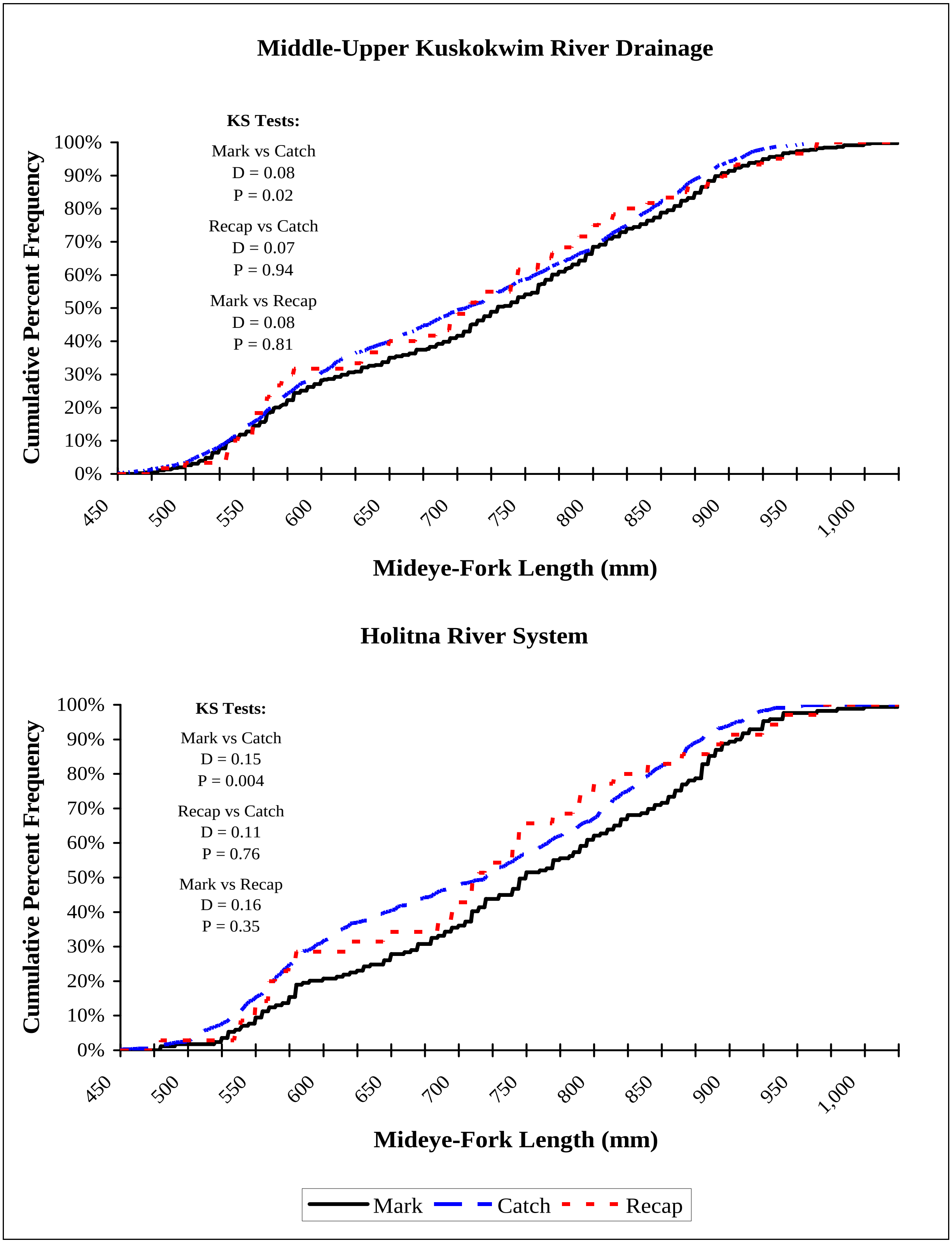

Figure 6.–Cumulative length frequency distributions comparing all Chinook salmon caught during the first (Mark) and second (Catch) events, and all recaptured (Recap) fish caught during the second event from the mark-recapture experiment in the Kuskokwim River and for the Holitna River, 2006.

estimates are estimated, these values had to be weighted. The potential for size bias during the marking event was examined by testing the null hypothesis that there was no difference between the length distributions of Chinook salmon that passed through the weirs during the second event and those "recaptured" during the second event. A significant difference was not detected when all fish were examined (D=0.07, P = 0.94), and likewise no difference was detected when examining only those fish bound for the Holitna River drainage (D = 0.11, P = 0.76). Length distributions of all Chinook salmon marked during the first event and those sampled for age, sex, and length during the second event were significantly different (D = 0.08, P = 0.02). A similar outcome comparing the marked vs. catch portions was also seen for the Holitna River system (D = 0.15, P = 0.004). However, the previous tests indicated no significant size bias sampling for both the mainstem and Holitna River fish and the sample sizes for the first and second events were relatively large (35 and 60 recaptures and respectively). Therefore, it can be concluded that the tests between the first and second event fish were likely showing small differences that have little potential to result in bias during estimation (Appendix A1).

After the series of diagnostic tests to detect violations of the assumptions of equal probability of capture, it was concluded that both the Kuskokwim River and Holitna River experiments were Case I (Appendix A1) experiments. Using an unstratified model, the abundance of Chinook salmon ≥450 mm for the Kuskokwim River upstream of the capture site and including the Aniak River was estimated at 233,133 fish (SE=28,450) with a 95% credibility interval of 187,600 to 299,200. An inriver abundance estimate was calculated that excluded Aniak River bound Chinook salmon (165,538, SE = 22,660). Because the Aniak River population was censored from the final estimate in previous years, this number was estimated for comparison purposes (Table 11). The abundance of Chinook salmon ≥450 mm that entered the Holitna River drainage

Table 11.–Estimated abundance with associated standard errors for Chinook salmon in the Kuskokwim River above the mouth of the Aniak River and in the Holitna River, 2002-2006.

	Kuskokwim River Drainage Above the Aniak River		Holitna River		% Mainstem Marked Fish (First Event) that Traveled up the Holitna River
Year	Abundance	SE	Abundance[a]	SE	
2002	100,733	24,267	42,902	6,334	42%
2003	103,161	18,720	42,013	4,981	48%
2004	146,839	21,980	81,961	11,722	48%
2005	145,373	15,528	72,690	8,510	48%
2006[b]	165,538	22,660	89,577	13,790	42%
2006[c]	233,133	28,450			

[a] Independent Holitna River estimates for 2002-2004 from Chythlook and Evenson (2003), and Stroka and Brase (2004), Stroka and Reed (2005).
[b] Inriver estimate for Chinook salmon above the confluence of the Aniak River.
[c] Inriver estimate for Chinook salmon above the tagging site near Kalskag and including the Aniak River drainage.

was estimated at 89,577 fish (SE=13,790) with a 95% credibility interval of 68,970 to 122,700. For all 5 years of the project, 42% to 48% of the total Chinook salmon escapement above the confluence of the Aniak River was estimated to have been made up of Holitna River drainage stocks (Table 11).

Age, Sex and Length Compositions

Diagnostic tests showed no significant gender selective sampling occurred during the first event. Ages were determined for 371 (82%) of the 454 first event Chinook salmon. The dominant age class for males was 1.3 and 1.4 for females (Table 12). In addition, age 1.3 and 1.4 have been the dominant age compositions for the previous four seasons (Table 13). Males comprised 54% of the 371 samples. Lengths of males ranged from 465 to 1,025 mm and lengths of females ranged from 480 to 970 mm (Figure 7).

Table 12.–Estimated proportions, abundance, and mean length at age for male and female Chinook salmon that were marked during the first event near Kalskag, 2006.

						MEF Length (mm)			
Age[a]	Proportion[b]	SE[c]	Abundance[b]	SE[c]	Sample Size[d]	Mean	SE	Min	Max
				Male					
1.2	0.17	0.02	39,589	6,690	63	566	3	465	725
1.3	0.23	0.02	53,413	8,344	85	715	3	510	905
1.4	0.13	0.02	30,163	5,546	48	831	4	565	1,025
1.5	0.01	0.00	1,885	1,132	3	868	21	780	980
Total	0.54	0.03	125,050	16,470	199	698	2	465	1,025
				Female					
1.2	0.07	0.01	16,338	3,722	26	572	5	480	695
1.3	0.14	0.02	32,048	5,787	51	724	4	470	930
1.4	0.24	0.02	55,927	8,626	89	843	3	555	965
1.5	0.02	0.01	3,770	1,620	6	893	13	850	970
Total	0.46	0.03	108,083	14,540	172	768	2	470	970
Total Male and Female			233,133	28,450	371	731	1	465	1,025

[a] Age is represented by the number of annuli formed during river and ocean residence. Therefore, an age of 1.4 represents one annulus formed during river residence and four annuli formed during ocean residence. Because a fish is 1 year old when the first annulus is formed, an age 1.4 fish is 6 years old.

[b] Proportion and abundance estimates were based on the age, sex and length data acquired from the first event sample that was first stratified to eliminate variability in capture probability.

[c] Estimates of SE were derived from posterior distributions of the parameter estimates that were produced using an empirical Bayesian analysis.

[d] Values represent actual fish sampled from the first event. All were ≥450 mm.

Table 13.–Abundance at age composition for Chinook salmon from the Kuskokwim River, 2002-2005.

	Age Composition[a, b]							
	3 years	4 years	5 years		6 years		7 years	
	1.1	1.2	1.3	2.2	1.4	2.3	1.5	2.4
2002								
Proportion	<0.01	0.16	0.40	<0.01	0.40	-	0.03	-
Abundance (100,733)	54	16,567	40,542	127	40,436	-	3,007	-
SE	54	5,740	12,699	85	10,180	-	924	-
2003								
Proportion	-	0.11	0.35	-	0.48	-	0.06	-
Abundance (103,161)	-	10,856	36,015	-	49,835	-	6,455	-
SE	-	2,396	5,234	-	9,829	-	2,034	-
2004								
Proportion	<0.01	0.35	0.31	<0.01	0.33	-	0.01	-
Abundance (146,839)	92	52,090	44,364	92	48,577	-	1,624	-
SE	98	9,491	7,370	98	10,091	-	641	-
2005								
Proportion	<0.01	0.14	0.49	<0.01	0.30	<0.01	0.06	<0.01
Abundance (145,373)	9	19,979	70,707	545	44,487	536	8,574	536
SE	21	5,792	8,023	545	5,929	542	2,276	548

[a] Age is represented by the number of annuli formed during river and ocean residence. Therefore, and age of 1.4 represents one annulus formed during river residence and four annuli formed during ocean residence. Because a fish is 1 year old when the first annulus if formed, an age 1.4 fish is 6 years old..

[b] Age composition for 2002-2004 are from second-event samples and that for 2005 and 2006 (Table 12) are from first event samples.

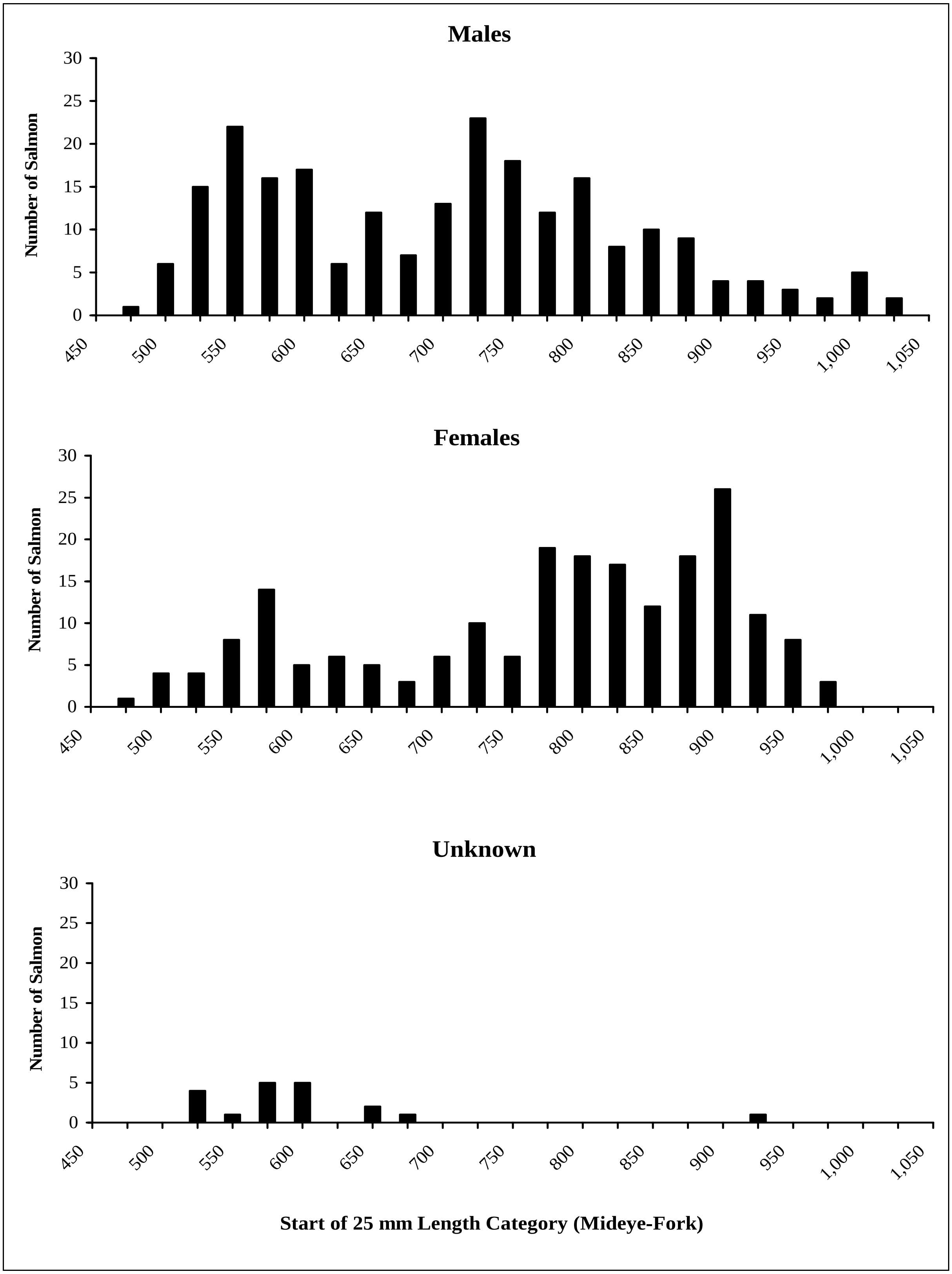

Figure 7.–Length frequency distributions of male and female Chinook salmon and those of unknown gender that comprised the First Event for 2006.

DISCUSSION

Radiotelemetry was successfully utilized as a means of distinctly marking Chinook salmon to estimate annual abundance within the middle to upper portions of the Kuskokwim River, which is large and occluded from visual enumeration methods. During each of the five seasons, deploying 500 radio tags proportional to run strength and fish size while equalizing sampling effort between north and south river banks proved to be challenging, despite utilizing a combination of gear types. After tags were deployed, a combination of stationary tracking stations coupled with aerial survey methods allowed the movements of 97-99% of the radio-tagged salmon to be recorded. Deploying and attempting to recover conventional spaghetti tags would not have provided for this level clarity of the overall fates of nearly all of the fish tagged. Also, because the number of marked fish passing through the weirs was known, the total weir count could be used for the second sample, not just the numbers of fish actually inspected for marks at the weirs. Therefore, the total number of fish that needed to be tagged in this experiment to acquire a precise estimate of abundance was smaller than what would be needed if conventional tags were used. Radio tags are much more expensive than spaghetti tags, but, the additional first and second event sampling effort to achieve similar results with spaghetti tags would have also been costly.

Due to the limited number of radio tags available, for the five years of the study, a tagging schedule was used based on test net data averages from the Kuskokwim River near Aniak that was conducted from 1992-1995. However, as could be seen from the five years of this study as well as the individual years of the test net study, migration timing and composition of the run varied from year to year. For instance, to distribute the radio tags according to the schedule was not possible in years like 2006 where the run was over a week late due to a late break up of the Kuskokwim River. For other years, to have distributed radio tags according to the schedule could have violated the assumption of equal catchability with respect to timing of migration. This assumption was violated in 2002 resulting in the use of a temporally stratified estimator (Darroch 1961) and subsequent loss of precision in the final estimate. Therefore, the tagging schedule was used as a bench mark of past run strengths while the project biologist kept tabs on the concurrent run strength of the ongoing Bethel Test Fishery near Bethel and catches from local subsistence fishers and tried to alter the schedule to best fit what was actually occurring for the particular field season.

For the 5 years of this study, radio-tagged Chinook salmon bound for the Aniak River demonstrated bank orientation at the marking sites, while no bank orientation was detected among salmon migrating to other spawning tributaries (Stuby 2003-2006). Bank orientation can indicate a significant potential for violation of the assumptions of equal probability of capture and can lead to a biased estimate of abundance. For 2002-2005, no second event sampling was conducted within the Aniak River drainage in order to assess whether Aniak fish were marked in similar proportion to other stocks. As a result, the Aniak River Chinook salmon were excluded from the final inriver abundance estimate. After bank orientation was detected for the first three seasons, the study objectives were altered for 2005 and 2006 so that inriver abundance would be estimated for Chinook salmon above the Aniak River instead of above the tagging sites near Kalskag.

In 2006, CFD placed a weir near the mouth of the Salmon River, a major tributary of the Aniak River, in an attempt to acquire a marked:unmarked ratio of Chinook salmon and as a means of enumerating and examining other species of salmon. The weir and subsequent nearby tracking station allowed for the detection of radio-tagged Chinook salmon from the mainstem tagging efforts near Kalskag in addition to providing for an estimate of escapement for this tributary. The enumeration, recapture, and composition (age, sex, length) data from the Salmon River was therefore included with that from the other three tributaries with weirs in subsequent analyses for equal probability of capture. As a result, the 2006 inriver estimate for Chinook salmon in the middle and upper portions of the Kuskokwim River drainage included Aniak River stocks.

Because salmon in general have a well-developed homing instinct, their choice of spawning river, tributary, and even riffle appears to be guided by long-term memory of specific odors (Groot and Margolis 1991). In an attempt to tag Chinook salmon below where they detect and then bank orient themselves to Aniak River discharge, tagging effort was relocated from the original location in 2002, to as far downriver in 2004 as was feasible. The approximate location within the Kuskokwim River drainage where Aniak River bound Chinook salmon begin to detect and respond to their natal water remains unknown. Sampling farther downstream than was done in 2004 would not have been feasible because the subsistence and commercial fisheries become more concentrated, thus making it more likely that a large number of radio-tagged fish would be harvested. Also, below Kalskag the Kuskokwim River widens and slows and suitable drift net and fish wheel sites (not already occupied by subsistence fishers) would have been difficult to locate.

The relative precision of the estimates have varied for the 5 years of this study. Having to censor various amounts of Aniak River bound Chinook salmon as well as other uncontrollable events have affected the quantity and quality of the data available for final analyses. In 2002, as a result of unknowingly sampling Aniak River bound Chinook salmon at a probable milling location near the Aniak River slough, a large number of fish had to be censored from the first event. In addition, due to the dissimilarity of marked:unmarked ratios of fish sampled at the four weirs, a temporally stratified estimator (Darroch 1961) was required to estimate abundance, resulting in a less precise estimate than desired. As a result of moving the first event sampling sites downriver the following year, a proportionately smaller numbers of Aniak River bound Chinook salmon needed to be censored. However, in 2003, numerous high water events throughout the summer curtailed weir operations, so the number of fish examined at the weirs and the number of recaptured fish was lowered. In 2004, new fish wheel and drift gillnet locations were not as productive for capturing Chinook salmon as sites used upriver in previous years; however, the relatively large samples from the four weirs led to more precise estimates of inriver abundance and age, sex, and length compositions. The relative precision of the 2005 and 2006 estimates was higher than for the first three seasons. The best drift gillnet and fish wheel spots that were gleaned from previous years were utilized and therefore most of the radio tags were deployed; and the number of days that the weirs were inoperable due to high water events were minimal.

The Holitna River drainage has been shown to support the largest Chinook salmon escapements within the middle-upper Kuskokwim River. Since the project’s inception, 42% to 48% of the total marked portion and approximately 55% to 72% of the recaptured fish have been bound for this tributary. Due to the relatively large number of radio-tagged fish that have traveled into this drainage, the Chinook salmon abundance estimates for the mainstem Kuskokwim and Holitna rivers have not been statistically independent because the same marked fish have been used in part for both estimates and the Kogrukluk River weir has been a major part of the second sample for both estimates.

The large variation in travel times seen for the approximately 6% the radio-tagged Chinook salmon for the 5 years of the study from the capture site to the various tracking stations were mainly a result of milling and roaming behavior. Lesser degrees of this behavior could vary from overshooting the spawning final destination and/or traveling back and forth past a tracking station while en route to spawning areas. A few fish every year have shown comparatively larger degrees of roaming. For example, in 2006 one radio-tagged Chinook salmon traveled downriver past the lowermost tracking station, returned 12 days later and then traveled up to Big River. Another fish from 2006 milled between the tracking station near Birch Tree Crossing and the two tracking stations located above and below Aniak for 48 days before finally traveling upriver and crossing the Kogrukluk River weir. It was assumed that capture, handling, and implanting radio transmitters did not affect the rates of fish movement. According to Matter and Sandford (2003), adult Chinook salmon that had pit tags implanted into them as juveniles showed similar migration rates between dams on the Columbia River as Chinook salmon that were captured as adults and fitted with esophageal implant radio tags.

Milling and roaming behavior is contrary to what would be expected for long-distance migrants like Chinook salmon that need to be efficient in their use of energy and minimize swimming costs wherever possible Hinch and Rand (2000). It has been hypothesized that salmon species use rheotaxis and odor recognition to navigate through river networks, using upstream rheotaxis in the presence of home stream odors, lateral searching or upstream zigzagging along tributary plume boundaries when cues are mixed, or downstream retreat when odors are absent (Quinn 2005). According to Keefer (2006), these behaviors may balance the costs and benefits of efficient homing with the energetic constraints imposed by moving through a complex flow environment. A potential cost of conditioned rheotaxis is that salmon that infrequently sample cues along both shorelines may be more likely to miss natal confluences and then have to travel back downstream, sometimes for the long distances that have been occasionally seen in the years of Kuskokwim River Chinook salmon study. Thus, the project biologist would not assign final fates to radio-tagged Chinook salmon until all of the tracking station, aerial, and tag return data had been gathered at the conclusion of the field seasons.

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APPENDIX A: STATISTICAL TESTS FOR ANALYZING DATA FOR SEX AND SIZE BIAS

Appendix A1.–Detection of size and/or sex selective sampling during a two-sample mark-recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g., Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/sex selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

-continued-

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and,} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right). \tag{2}$$

where: j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;

$\hat{N}_i$ = the estimated abundance in stratum *i*; and,

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Tests of consistency for Petersen Estimator

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during the first event; or,
3. Every fish has an equal probability of being captured and examined during the second event.

To evaluate these three assumptions, the chi-square statistic is used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) will be used to estimate abundance.

I.-Test For Complete Mixing[a]

Area/Time Where Marked	Area/Time Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
S					

II.-Test For Equal Probability of Capture During the First Event[b]

	Area/Time Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test For Equal Probability of Capture During the Second Event[c]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from area or time i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among area or time designations: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among area or time designations: H0: Σjθijpj = d, where pj is the probability of capturing a fish in section j during the second event, and d is a constant.

APPENDIX B: ARCHIVED DATA FILES FOR 2006

Appendix B1.–Data files used to estimate parameters of the Chinook salmon population in the Kuskokwim River, 2006.

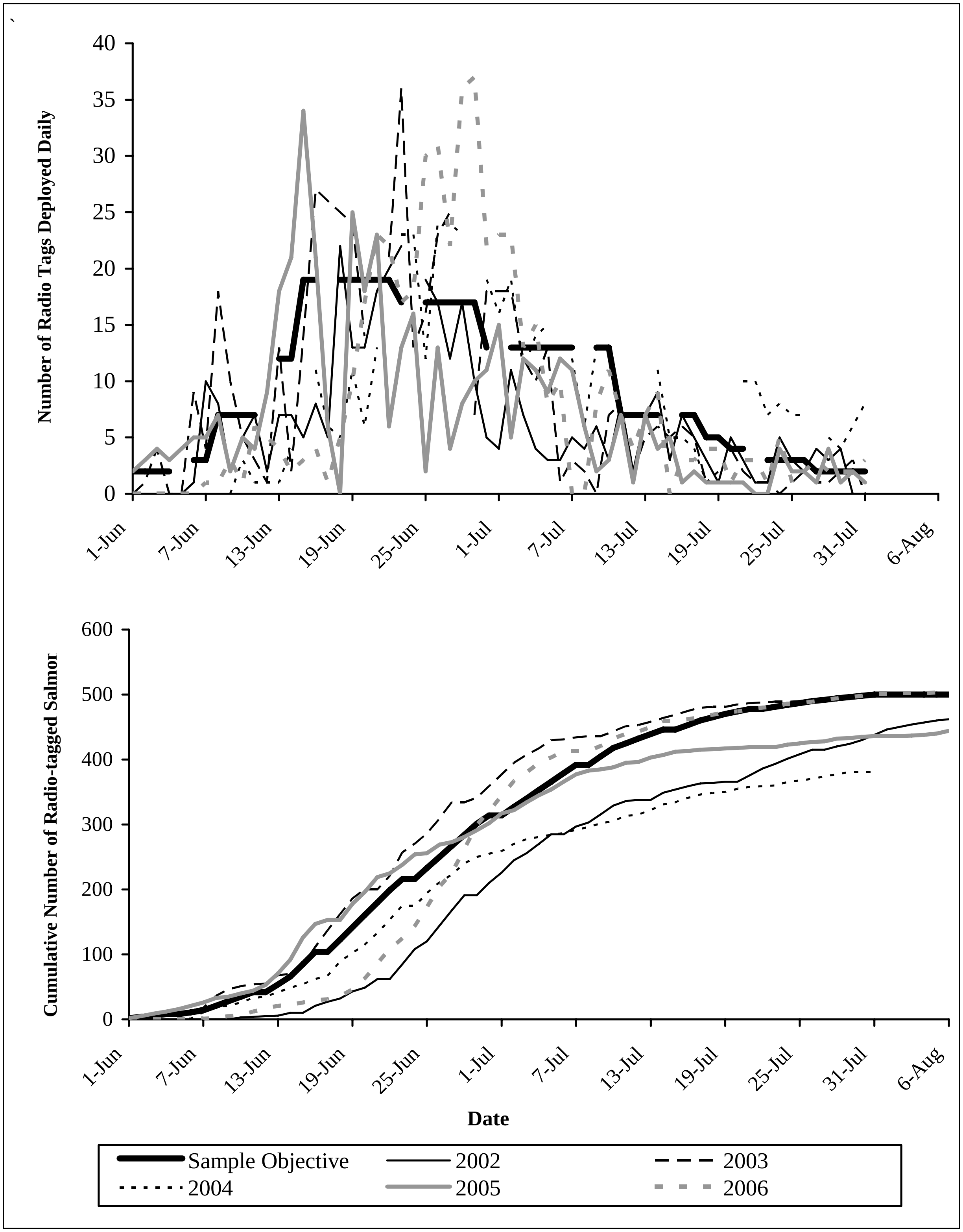
Data File	Description
George Chinook 06.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the George River weir, 2006.
Kogrukluk Chinook 06.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Kogrukluk River weir, 2006.
Takotna Chinook 06.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Takotna River weir, 2006.
Tatlawiksuk Chinook 06.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Tatlawiksuk River weir, 2006.
MEF Kusko River Esc Data-Kogrukluk.xls[a]	Excel spreadsheets with daily and historical counts of Chinook salmon passage through the Kogrukluk River weir, 1976-2006.
MEF Kusko River Esc Data.xls[a]	Excel spreadsheets with daily and historical counts of Chinook salmon passage through the George, Tatlawiksuk, Takotna, and Salmon river weirs, 1995-2006.
2006 Data.xls[b]	Excel spreadsheets with consolidated capture, aerial, and tracking station data. File also includes determination of fates, final destinations of radio-tagged Chinook salmon, and analyses of bank of mark to final fate for 2006.
ASL 2006.xls[c]	Excel spreadsheets with consolidated age, sex, and length data from the George, Tatlawiksuk, Kogrukluk, Takotna, and Salmon river weirs. File also contains results from contingency table analysis testing for sex bias and the KS tests that examined size bias for the mark-recapture experiment for 2006.
Tagging schedule and totals for 2006.xls[c]	Excel spreadsheets with daily sampling objectives and actual numbers of Chinook salmon captured and radio-tagged in 2006.
Estimate Analysis 2006.xls[c]	Contingency table analyses to test assumptions for the mark-recapture experiment, 2006.
Migration Times 2006.xls[c]	Excel spreadsheets include travel times of radio-tagged Chinook salmon to all of the tracking stations, run timing of radio-tagged fish into the major tributaries of the Kuskokwim River, and analyses of run timing differences between fish sampled with drift gillnets vs. fish wheels, 2006.

[a] Data files have been archived and are available from the Alaska Department of Fish and Game, Commercial Fisheries Division, 333 Raspberry Road, Anchorage, 99518-1565.

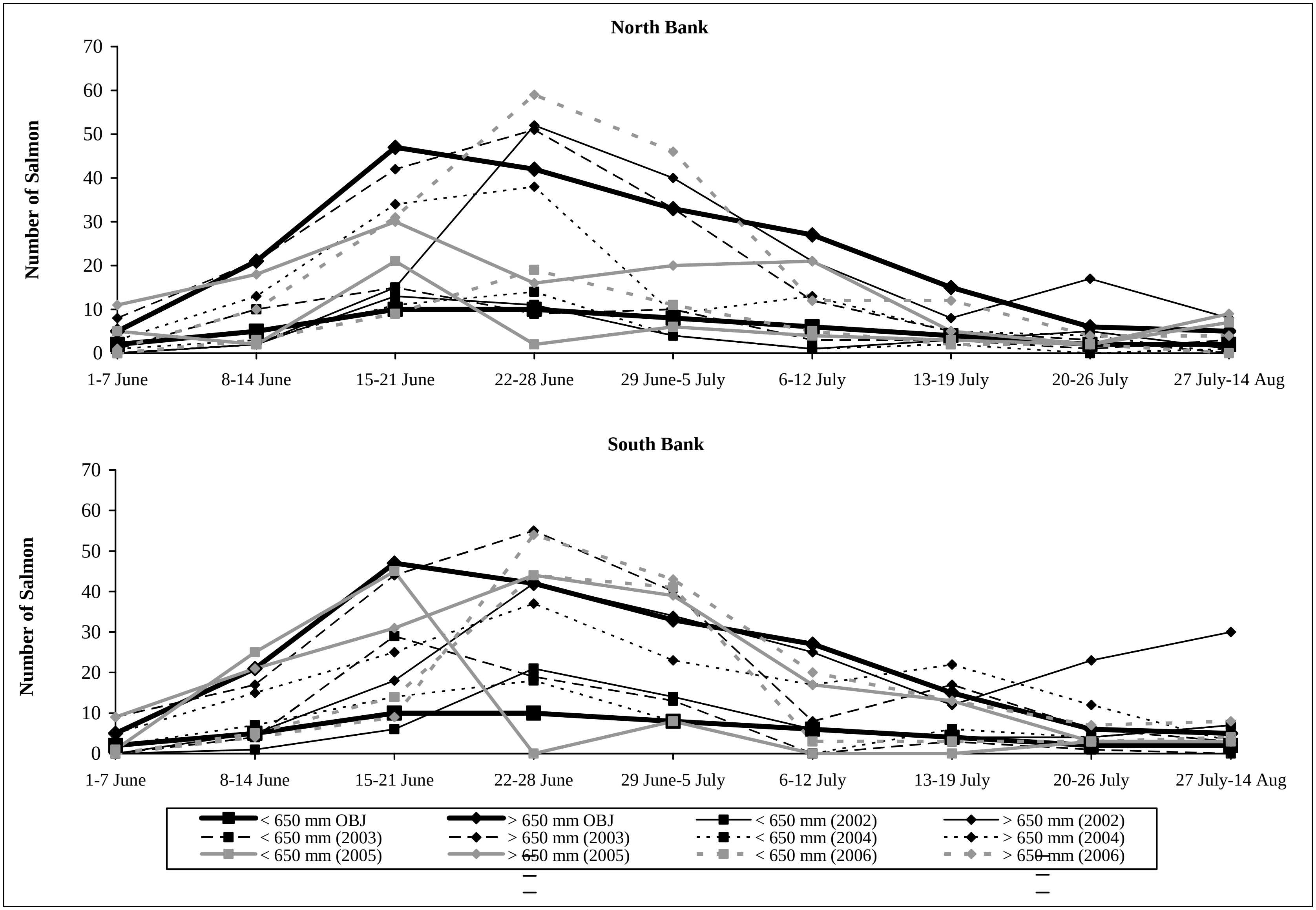
[b] Data files have been archived and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage 99518-1565.

[c] Data files have been archived at the Alaska Department of Fish and Game, Division of Sport Fish, 1300 College Road, Fairbanks, Alaska 99701 and are available from the author.

APPENDIX C: SAMPLING OBJECTIVES AND ACTUAL DAILY NUMBER OF CHINOOK SALMON SAMPLED FOR 2002-2006

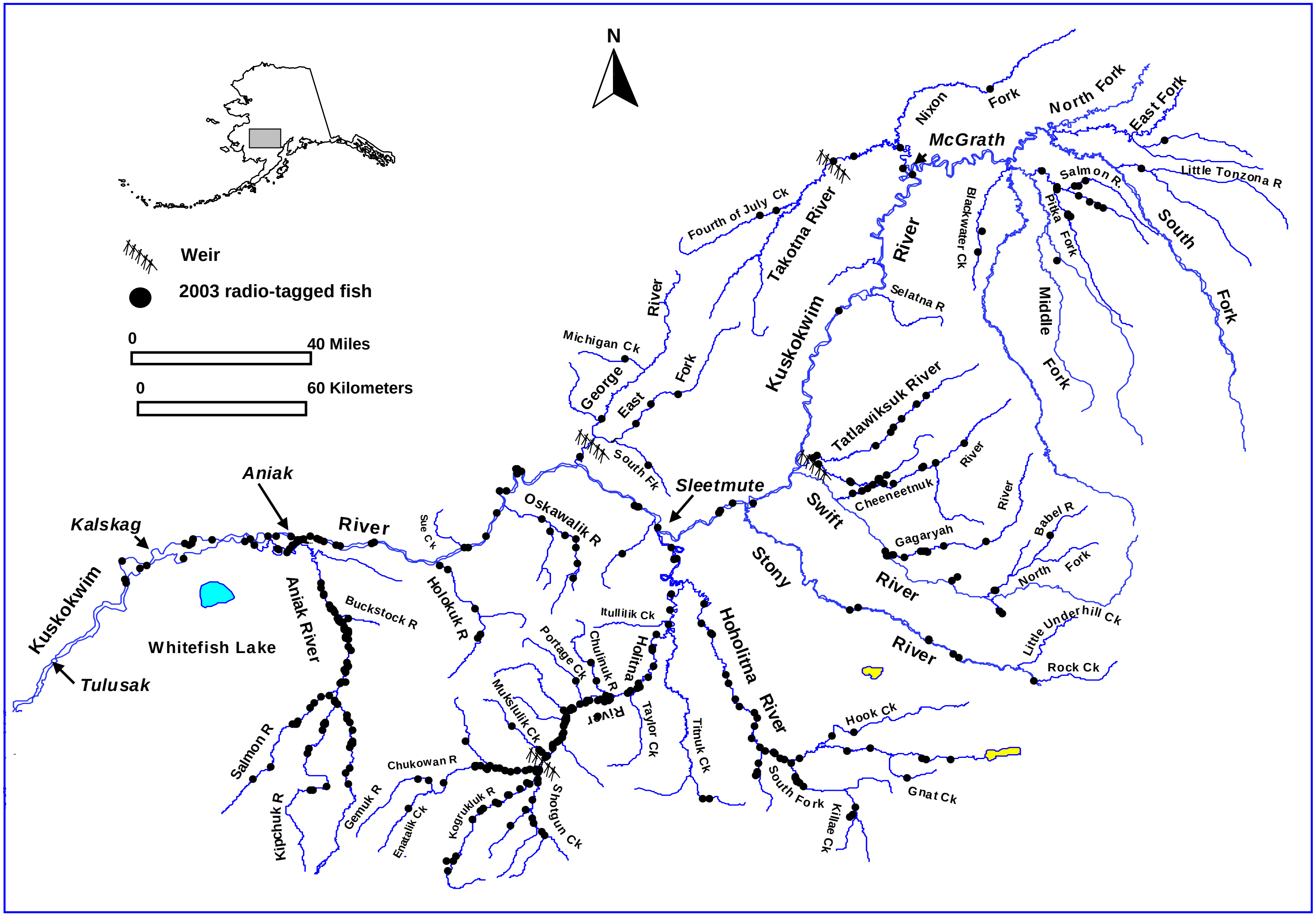


Appendix C1.–Daily and cumulative number of Chinook salmon that were radio-tagged in the Kuskokwim River versus the sampling objective for 2002-2006.

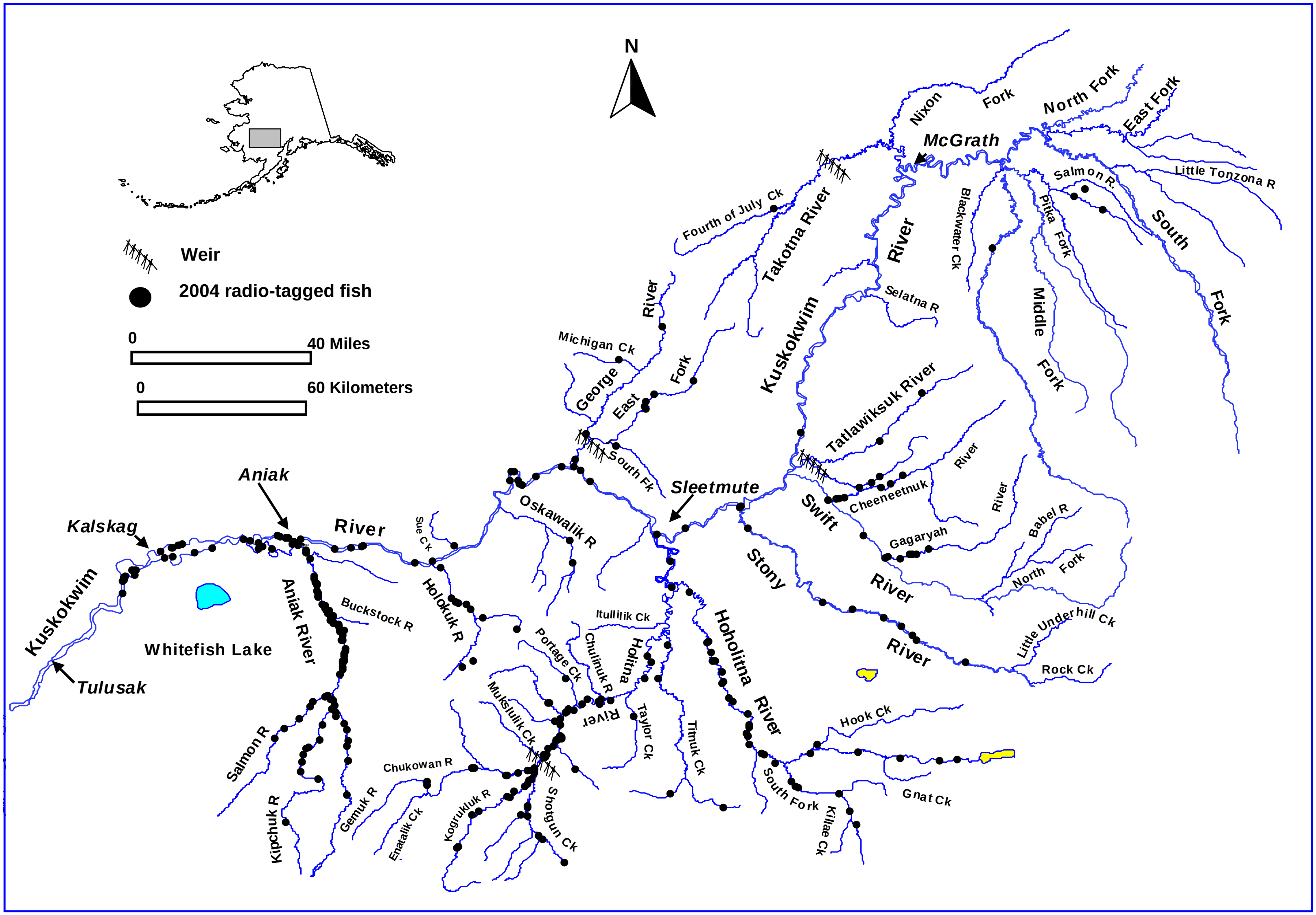


Appendix C2.–Chinook salmon size classes sampled and radio-tagged on the north and south banks of the Kuskokwim River (Actual) versus the pre-season objectives (OBJ) for 2002-2006.

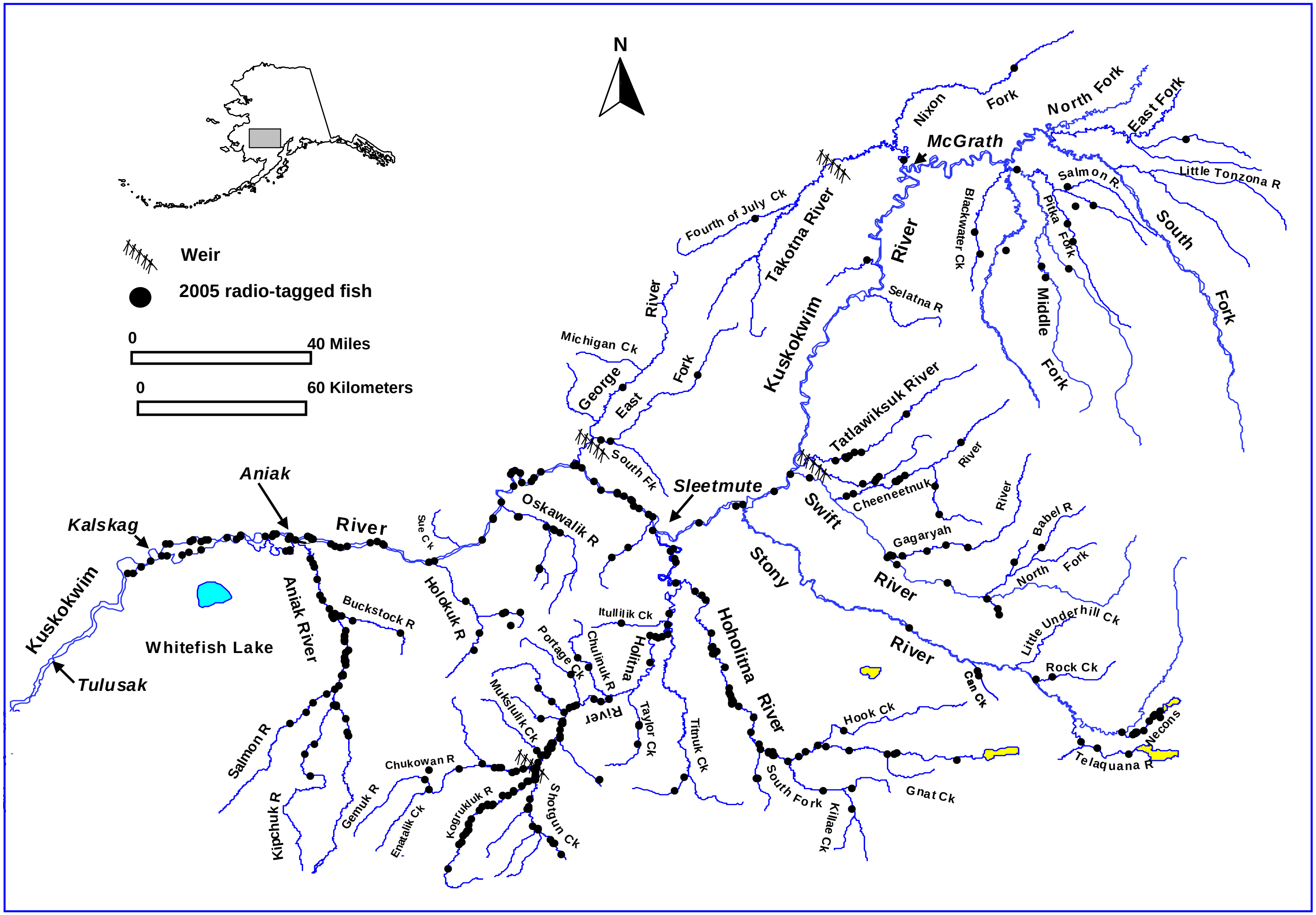
APPENDIX D: APPROXIMATE UPPERMOST EXTENT OF CHINOOK SALMON DETECTED DURING THE JULY AND AUGUST AERIAL SURVEYS FOR 2003-2006



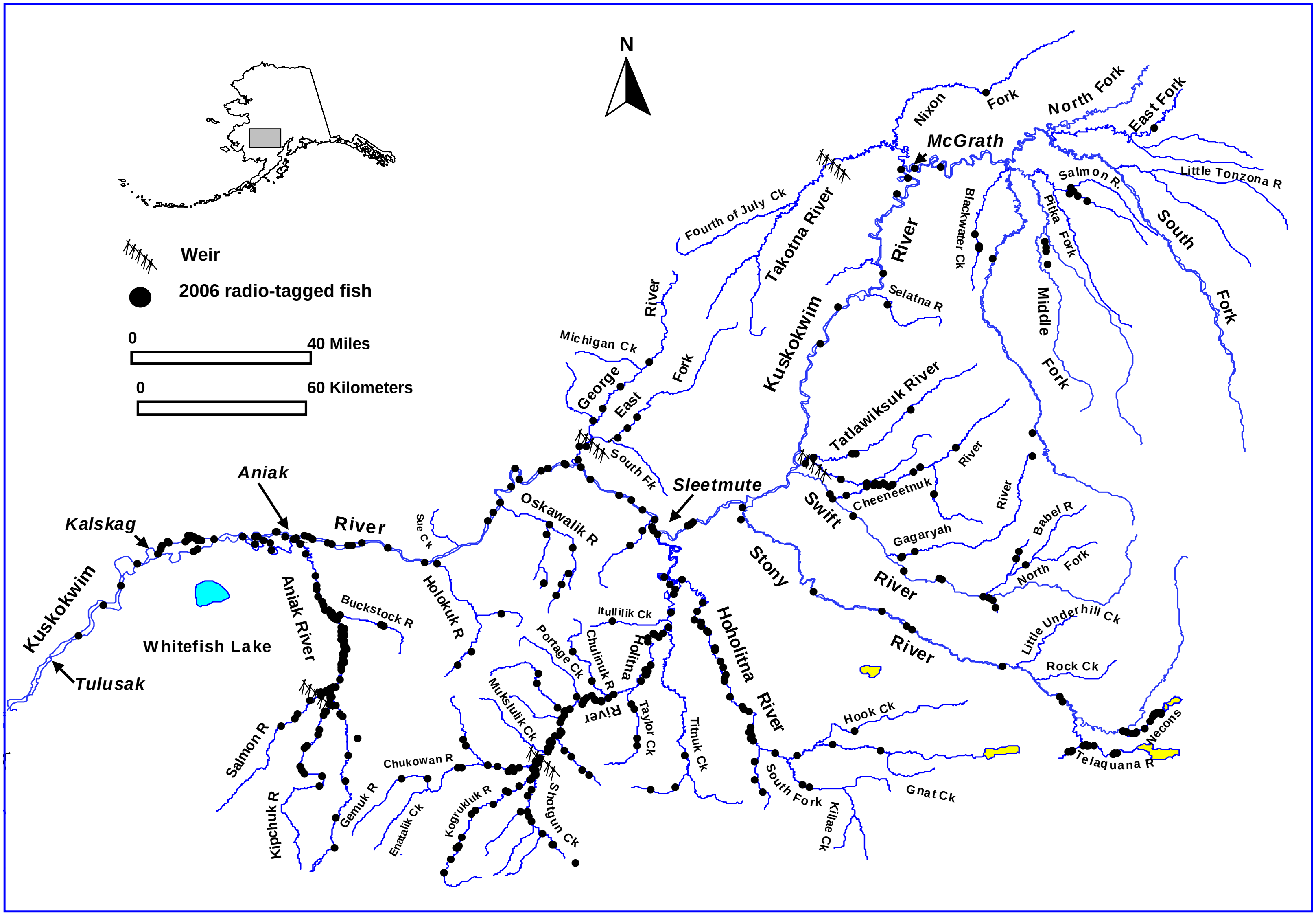
Appendix D1.–Map of the Kuskokwim River drainage showing the approximate uppermost final locations of radio-tagged Chinook salmon that were detected during the July and August aerial survey flights in 2003. Only those drainages covered by aerial means are shown.



Appendix D2.–Map of the Kuskokwim River drainage showing the approximate uppermost final locations of radio-tagged Chinook salmon that were detected during the July and August aerial survey flights in 2004. Only those drainages covered by aerial means are shown.



Appendix D3.–Map of the Kuskokwim River drainage showing the approximate uppermost final locations of radio-tagged Chinook salmon that were detected during the July and August aerial survey flights in 2005. Only those drainages covered by aerial means are shown.



Appendix D4.–Map of the Kuskokwim River drainage showing the approximate uppermost final locations of radio-tagged Chinook salmon that were detected during the July and August aerial survey flights in 2006. Only those drainages covered by aerial means are shown.